

VOLUME XVIII
NUMBER 5.

AUGUST
SEPTEMBER 1901.

Annual Subscription \$5.00
Single Copies 30

TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.



CONTENTS.

The Electric Transmission of Power From Niagara Falls. By L. B. Sillwell, Aug. 23rd, 1901.	541
Notes on Modern Electric Railway Practice. By Albert H. Armstrong, Aug. 24, 1901.	628
Electric Railway Apparatus. By Ernst J. Berg, Aug. 24, 1901.	643
An Improved Apparatus for Arc Light Photometry. By Charles P. Matthews, Sept. 27th, 1901.	671
Advertisements.	684

PUBLISHED MONTHLY BY THE INSTITUTE, UNDER THE SUPER-
VISION OF THE EDITING COMMITTEE.

[CONVENTION 1901, BY AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.]

RALPH W. POPE, Secretary.

30 CORTLAND STREET, NEW YORK CITY.
Telephone, 2121 Cortlandt.

OFFICERS AND BOARD OF DIRECTORS, 1901-1902.

PRESIDENT:

CHARLES P. STEINMETZ.
Term expires 1902.

JUNIOR VICE-PRESIDENTS:

Dr. A. E. KENNELLY, CARL HERING.

VICE-PRESIDENTS:

Terms expire 1902.
ARTHUR V. ABBOTT,
GANO S. DUNN,
W. L. E. EMMET.

Terms expire 1902.
Dr. MICHAEL I. FUPIN,
Dr. SAMUEL SHELTON,
GEORGE F. SEVER.

MANAGERS:

Terms expire 1902.
C. O. MAILLOUX,
WILLIAM D. WEAVER,
CHARLES S. BRADLEY,
TOWNSEND WOLCOTT.

Terms expire 1902.
JOHN J. CARTY,
W. S. HAKSTOW,
RALPH D. MERSHON,
CALVIN W. RICE.

Terms expire 1902.
JOHN W. LIEB, Jr.,
CHARLES F. SCOTT,
Prof. W. GOLDSBOROUGH,
Col. SAMUEL REBER.

TREASURER:

GEORGE A. HAMILTON,
215 West Street, New York.

SECRETARY:

RALPH W. POPE,
26 Cortlandt St., New York.

PAST-PRESIDENTS.

Dr. NORVIN GREEN, 1882-3-4.
FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
Prof. ELIHU THOMSON, 1889-90.
Prof. W. A. ANTHONY, 1890-91.

ALEX. GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-3.
Dr. EDWIN J. HOUSTON, 1893-4-5.
Dr. LOUIS DUNCAN, 1894-5-7.
Dr. FRANCIS B. CROCKER, 1897-8.
Dr. A. E. KENNELLY, 1898-1900.

CARL HERING, 1900-1901.

Standing and Special Committees:

STANDING COMMITTEES.

Executive Committee.

CHARLES P. STEINMETZ, Chairman.
JOHN J. CARTY, CALVIN W. RICE.
GANO S. DUNN, WM. D. WEAVER.
GEO. A. HAMILTON, Other members not yet appointed. RALPH W. POPE.

Board of Examiners.

WILLIAM MAVER, Jr., Chairman.
ROBERT N. BAYLIS, JESSE M. SMITH.
F. A. PICKERNELL, TOWNSEND WOLCOTT.

Committee on Papers.

CALVIN W. RICE, Chairman.
C. O. MAILLOUX, Dr. SAMUEL SHELTON.
T. COMMERFORD MARTIN, CHARLES A. TERRY.

Committee on Finance.

JOHN J. CARTY, Chairman. Editing Committee.
C. O. MAILLOUX, GANO S. DUNN, Chairman.
CALVIN W. RICE, EDWARD CALDWELL,
HENRY A. LARDNER.

Library Committee.

WILLIAM D. WEAVER, Chairman.
EDWARD CALDWELL, W. J. JENKS.
GANO S. DUNN, CHARLES E. KNOX.

SPECIAL COMMITTEES.

Committee on Standardisation.

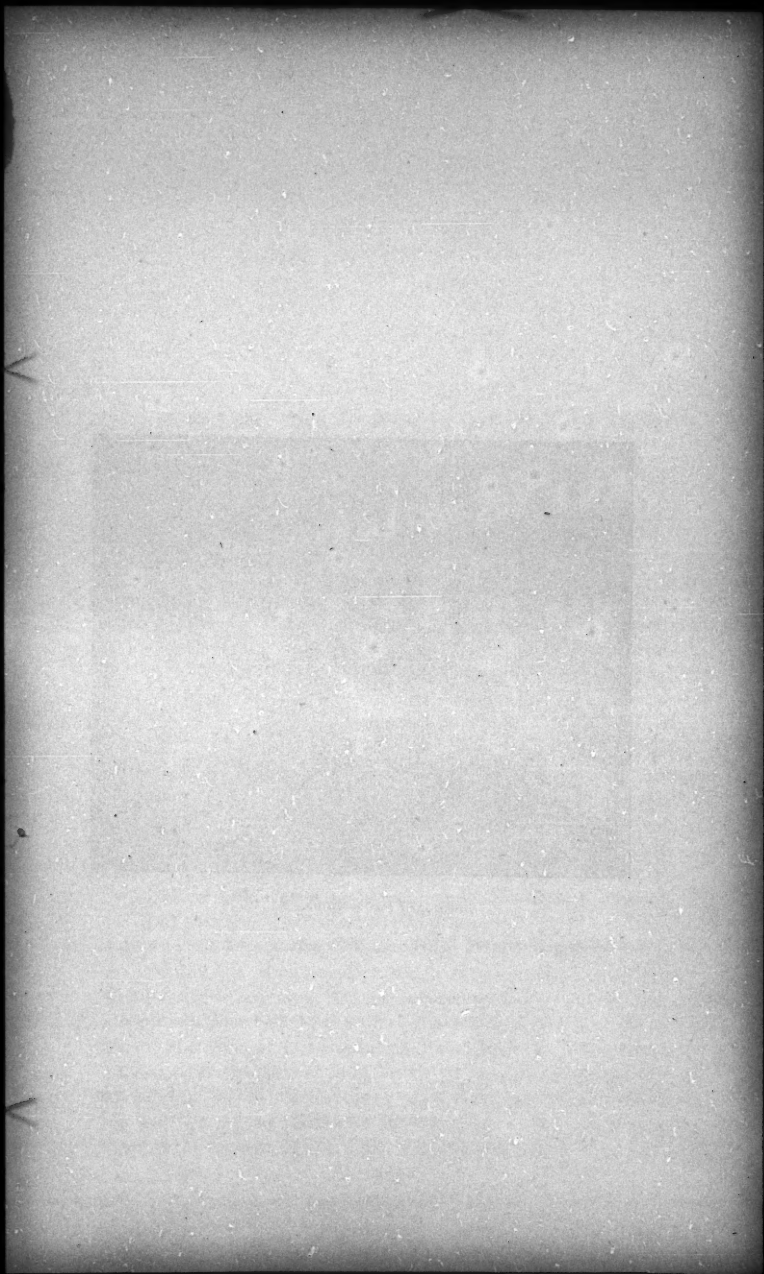
Dr. FRANCIS B. CROCKER, Chairman.
Dr. ARTHUR E. KENNELLY, JOHN W. LIEB, Jr., CHARLES P. STEINMETZ.
LEWIS E. STILLWELL, Prof. ELIHU THOMSON.

Reception Committee.

T. COMMERFORD MARTIN, Chairman. WILLIAM J. HAMMER, E. T. E. LOZIER,
CHAS. T. CHILD, CALVIN W. RICE.
C. O. MAILLOUX, Dr. SAMUEL SHELTON.

Committee on By-Laws.

CARL HERING, Chairman.
GANO S. DUNN, JOHN W. LIEB, Jr., RALPH W. POPE.
CALVIN W. RICE, WILLIAM D. WEAVER.





Interior of Power House No. 1.

THE ELECTRIC TRANSMISSION OF POWER FROM NIAGARA FALLS.

BY LEWIS B. STILLWELL.

I. INTRODUCTION.

The history of the Niagara Falls power plant is a demonstration of the ability of applied electrical engineering science to attain in commercial practice results predicated in large degree upon theory. In a most striking manner, it exhibits the fact that for nearly a decade electrical engineering has been established upon a basis as certain and permanent as other branches of engineering; that eight years ago—a long time in our profession—it was possible to so plan an electrical installation involving ultimately the transmission and distribution of several hundred thousands of horse-power that at the present time we can effect improvement only with respect to relatively unimportant details, the aggregate results of which, if adopted, would be hardly noticeable as affecting the cost of power. I think it safe to say that if the Niagara Falls Power Company to-day were facing the same problem which they solved in 1893 and should bring to bear upon it the same comprehensive and thorough-going methods which at that time characterized the work of its officers and directors, their solution, based upon all that has been learned up to the present time, would be so nearly identical with the solution which they adopted eight years ago that the resulting cost of power delivered to users would not be affected even to the amount of one dollar per kilowatt year.

These facts are perhaps in no sense surprising to members of this INSTITUTE, but the general public, and even many men of broad intelligence and large affairs, unquestionably still have a feeling that electrical engineering is in large degree experimental, and that capital invested in electrical enterprises to-day may vanish to-morrow by reason of some new invention. It is surely important to establish confidence in the certain and permanent character of adequate electrical engineering, and I shall ask you to consider the Niagara plant with special reference to two thoughts, viz., (1) How does the plant as it now stands completed differ from the plans contemplated in October, 1893, when the original contract for electrical machinery was closed; and (2) What has experience in the construction and operation of the first plant suggested in the way of further improvement? The history of the plant considered with these thoughts in mind constitutes a forceful reply to the statement so often made that "electricity is in its infancy," and should go far to establish confidence in the ability of electrical engineering science to predict with accuracy results that are reasonably certain to be realized in practice.

In saying that if the Niagara Falls Power Company in 1901 were facing the problem which they solved in 1893, the solution now would be substantially identical with the solution then, I am not saying that there has been no important improvement in electrical methods and machinery during the last eight years. Undoubtedly the art has advanced; methods of manufacture by reason of accumulated experience and improved facilities are far more satisfactory now than they were then. Our knowledge of theory, particularly the theory of alternating currents, is relatively far more complete, but progress in alternating current methods since 1893 has been in no sense revolutionary, and the time has long since passed when capital might reasonably hesitate to embark in well-considered enterprises depending for success upon a correct application of electrical engineering skill. It is a significant fact that the electrical machinery to be installed in the second power-house now under construction will differ from that now in use in power-house No. 1 with respect only to details of construction, relatively unimportant, while nearly every constituent part of the hydraulic equipment of the new plant will be materially and even radically different from its predecessor.

It has been said that electricity as a science is only less exact than astronomy, but the fact that a science is exact, by no means implies that there is but one reasonable way of applying it to the solution of an engineering problem. Naturally, in electrical engineering, as in other departments of human endeavor, several roads often lead to practically the same goal, and were a Niagara problem to be presented for solution to-day to the members of this INSTITUTE, I have no doubt that the plans proposed would exhibit sufficient variety to remove all fear that practice is liable to become so "standardized" as to leave no room for originality, new ideas and consequent progress, but I imagine that the plans proposed, while varied, would be by no means so widely divergent as they would have been in 1893. To the business man without technical training who may venture to read the discussion of a subject like this by an engineering society, the natural divergence of individual views expressed with respect to frequency, potential and all the rest must convey the impression that there is no such thing as established lines of practice, but when these differences of opinion are expressed in concrete units of cost it is apparent that considerable variety of detail in plan and construction may be consistent with attainment of the same practical result.

II. THE PROBLEM PRESENTED.

The wisdom or unwisdom of the plans adopted in 1893, upon which we now have the additional light of eight years' extraordinary activity in both theoretical and practical work, must be judged with reference to the conditions and requirements of the market for power then assumed rather than with reference to the requirements of the market as now actually developed. It was expected in 1893 that a very large proportion of the power developed would be utilized by motors in mill and factory work. With regard to the local use of power at Niagara, this anticipation has not been realized and even in Buffalo more than half the Niagara power used is utilized in operating the street railway and lighting systems.

In a descriptive memoir which I drew as Electrical Engineer of the Westinghouse Company, and which was submitted to the Cataract Construction Company under date of February 6, 1893, my understanding of the problem presented was stated as follows:

"We are to lay out a system that will enable you to take energy at the upper end of vertical shafts making 250 R. P. M., each shaft delivering 5000 H. P., and to deliver in saleable and reliable form the largest practical and economical percentage of this energy; 1st, within the limits of Cataract City, distance not exceeding two miles; 2d, at the northern boundary of the City of Buffalo, 3rd at more distant points, *e. g.*, New York and Chicago.

In each of the above cases energy is to be delivered in form available for :

1. Power purposes.
 - (a) General mill and factory work, pumping stations, etc.; units of from 10 to 1000 H. P.
 - (b) Operation of street railways; units of from 100 to 1000 H. P.
 - (c) Miscellaneous work in factories, mills, the operation of elevators, printing presses, etc.; units 1 to 25 H. P.
2. Lighting purposes.
 - (a) Arc lights.
 - (b) Incandescent lamps.
3. Electrolytic purposes.

It is proposed to ultimately locate twenty-five 5000-H. P. turbines at the power-station on the American side of the river, and upon the Canadian side of the river an as yet undetermined number of units of equal size. The distance between the power-stations, by way of the Suspension Bridge is $2\frac{1}{2}$ miles, and it is desired to provide electrical connection between the stations so that the generating apparatus in one station may in time of emergency be substituted for that in the other.

While the above stated capacities are to be ultimately installed, the immediate requirements are limited to three generating units of 5000-H. P. each, with whatever apparatus may be needed in connection therewith, first, to transmit and distribute energy within the limits of Cataract City; second, to transmit energy to a sub-station located at the northern boundary of Buffalo.

For electrolytic and power purposes the capacity of at least one machine will soon be called for at the manufacturing center, Echota, situated 7000 feet from the power-station on the American side of the river within the limits of Cataract City; from 200 to 300 H. P. will be needed for the operation of an electric freight and passenger railway, extending from the power-house by way of Echota to a junction with the New York Central Railway, situated near the northeastern limits of the new city of Niagara Falls.

It is proposed to employ one or two generators to supply power to a sub-station at the northern limit of Buffalo. The amount supplied will depend upon the market for power, and the system selected must be such as will admit of ready and symmetrical increase with the growth of the demand. As stated by Mr. Adams, the principal purposes for which power is now used in the city of Buffalo, with the approximate amounts for each, are:

Pumping.....	4,000 H. P.
Operation street railways.....	3,000 H. P.
Arc lighting.....	3,500 H. P.

In addition to this about 1,000 H. P. is used to supply incandescent lamps, and there is also a considerable amount of power used for miscellaneous purposes in factories and mills.

The ability to reach more remote markets for power,—as, for example, the cities of New York and Chicago,—will depend upon the practicability of properly insulating the conductors used for the transmission of currents. Recent progress in this direction has been such as already makes our available radius of transmission greatly exceed the distance between the power station and the city of Buffalo, and it is desirable that the system selected should be such as will lend itself to future transmission over very great distances.

In considering the above requirements we note, first, that the conditions impose the following as necessary characteristics of the system:

- 1st. Alternating currents for transmission.
- 2nd. Direct currents for electrolytic work.
- 3rd. Direct currents for street railway purposes.

For general power purposes, and for arc and incandescent light, the conditions are not restrictive, and we may use either alternating current or direct current. But while both alternating and direct currents are needed, it is in the highest degree desirable that the system should be so laid out as to admit uniformity in size and type of generators. This feature in an installation is of the greatest value, as it allows ready substitution of one generator for another when for any reason such substitution becomes desirable. It implies also uniformity in auxiliary station apparatus, and a symmetry of system which is invaluable in the practical operation of the plant."

III. THE SYSTEM ADOPTED.

The system chosen to meet the complex, and, up to that time unprecedented requirements was the alternating current system using two-phase alternators wound for 25 cycles per second and 2,200 volts. It was adopted as the result of a most comprehensive and pains-taking investigation conducted under the personal direction of Mr. Edward D. Adams, President of the Cataract Construction Company, assisted at every step from the inception of the enterprise by Dr. Coleman Sellers as his chief engineering adviser. It was adopted notwithstanding the fact that some of the greatest scientists of the day advised against the use of alternating current and in favor of direct current. That the

directors of the company in 1893 selected a system substantially identical with that which they would undoubtedly choose to-day to meet a similar problem is due in very large degree to the great ability and conscientious care of that grand old American engineer, Coleman Sellers, of Philadelphia, himself not claiming special knowledge of electricity, but possessed of vast experience in engineering science in many fields and excellently qualified to judge both electricians and their works.

The Cataract Construction Company, from the time when the directors and Dr. Sellers seriously began their study of the problem of utilizing Niagara power in 1889, to the time of closing the contract with the Westinghouse Electric Company, of Pittsburg, Pa., for the first three alternators, arrived at six important decisions with respect to engineering practice. These decisions were: (1) to use a central power station and a system of electrical power distribution, "as the chief means of distributing the power, though perhaps not the only means;" (2) to adopt a uniform system for both local and long distance transmission; (3) to use the alternating current system; (4) to reject the three-phase system; (5) to adopt a frequency of 25 cycles per second; (6) to use alternators wound for about 2,000 volts and step-up transformers for transmission to points not economically reached by the potential generated.

The decision to use a central power station developing power in large amounts by turbines located in a limited number of large wheel pits and to distribute power electrically instead of adopting an exclusively hydraulic development as generally used prior to that time in the development of water power for manufacturing purposes, was undoubtedly wise. To-day in new plants the utilization of water power is almost invariably accomplished by means of electrical distribution.

To adopt the alternating and not the direct current system was also undoubtedly wise. In 1893, however, there were still many who believed that the direct current system possessed superior advantages, but the development of the art of transmitting and distributing power has long since practically settled this question. There is nothing in the work of Thury, or others, who have attempted to utilize continuous currents at high potential for long distance transmission that would lead us to question the superiority of the alternating current system for long distance

transmission of power. The transformer is the key to the solution of this problem which those who had done most in the development of continuous current apparatus in 1893 were generally ready to admit could not be solved by continuous current methods.

The wisdom of the decision to reject the three-phase system is at least open to question. This decision was reached by the directors of the Cataract Construction Company in May, 1893. I am on record prior to that time, and in fact as far back as 1889, in advising the use of the two-phase system, but from present knowledge I believe that the decision to reject the three-phase system in May, 1893, was a mistake. At that time Charles F. Scott's clever invention of the method of winding and connecting transformers to secure three-phase currents from a two-phase source had not been announced and but for that invention it is my opinion that the additional cost of conductors required by the two-phase system would to-day turn the scale in favor of the three-phase plan. Under the conditions existing at Niagara, however, where single-phase power is required in a number of cases, the two-phase arrangement possesses a substantial advantage in the entire separation of phases and the convenient balancing of the load, and were a new Niagara problem to be presented to-day with conditions precisely such as are met by the existing plant, as we now have the means of obtaining three-phase currents for the more distant and therefore more expensive transmission, while using for local distribution either single-phase or two-phase circuits, I should still incline to the use of two-phase alternators.

As regards the frequency chosen, viz.: 25 cycles per second, experience since 1893 has demonstrated the wisdom of its selection. This frequency is to-day more generally used in America in electrical distribution for power purposes than any other. Personally, I consider 30 cycles preferable, but at Niagara it was not possible to adopt this frequency for the reason that the speed of the turbines had been fixed at 250 revolutions per minute before the question of frequency was seriously considered. A 16-pole dynamo at 250 R. P. M. will produce $33\frac{1}{3}$ cycles per second and a 12-pole dynamo twenty-five cycles per second. There were difficulties in the way of winding a 14-pole machine for two-phases, and after very careful consideration of the relative advantages of 25 cycles and $33\frac{1}{3}$ cycles the former was chosen.

My principal reason for believing that a frequency of 30 cycles per second is preferable to 25 cycles per second is that 110-volt incandescent lamps of 16-candle power or more, when supplied at that frequency from practically any commercial alternator, are free from any suspicion of fluctuation in candle power due to reversal of current, while at 25 cycles such is not the case. At Niagara, the town of Echota is satisfactorily lighted by incandescent lamps using 25-cycle currents, but this result is somewhat assisted by the fact that the potential wave of the Niagara alternators is flatter than a sine curve. A great deal depends upon the form of the E. M. F. wave, although I do not remember having seen this point mentioned in any of the published discussions of this subject. If the wave be pointed or peaked, *i. e.*, if the ratio of maximum to mean value of the E. M. F. during a half cycle materially exceed the ratio of these quantities in a sine wave, incandescent lamps will show visible fluctuation at frequencies considerably higher than is the case if a flattened wave be used. Of course a 110-volt lamp will show fluctuation under conditions when a 50-volt lamp will show none and presumably 220-volt lamps are still more sensitive, although I have never tested this experimentally. I have found no reason, therefore, to modify the opinion first formed in 1890, that for plants in which the supply of power is the principal object, 30 cycles, which, with absolutely satisfactory results, permits also direct supply of incandescent lamps, is the best frequency.

The alternators were wound to deliver 3,730 kilowatts at any desired potential not less than 2,000 volts and not exceeding 2,400 volts. My intention in thus defining the limits of working potential was to provide for drop in transmitting and distributing circuits using 2,000 volts as the general potential delivered to users of the power and allowing in the generators for an increase of potential at terminals amounting to 20%, which amount I considered might be necessary in undertaking very distant transmission at some future time. In some way which has never been clearly explained, the officers of the Cataract Construction Company apparently interpreted the phrase "from 2,000 to 2,400 volts" to mean 2,200 volts and the apparatus used by the first electrical tenant of the power company, *viz.*: The Pittsburg Reduction Company, which apparatus was supplied by the General Electric Company, was wound for 2,200 volts.

In this way, the delivered potential at Niagara, and subsequently for reasons of uniformity in Buffalo, was fixed at 2,200 volts. The reasons for choosing a potential of about 2,000 volts are indicated by the following quotation from a letter which I wrote October 2, 1893:

"We should mount the fields of the generators upon the extended turbine shafts and should wind the stationary armatures to deliver current at a potential of from 2,000 to 2,400 volts. This potential is well adapted to your work in Cataract City. It is sufficiently high to secure good economy in the system of distribution, and it is not so high as to impose special difficulty and danger in the insulation of the circuits and the manipulation of the switching devices. Motors may be operated from circuits conveying current at this potential without the use of step-down transformers.

For transmission to Buffalo and other distant points, we should advise a high potential, say 10,000 volts, obtained by step-up transformers. If possible, these transformers should be so designed and the units so selected as to permit an increase in potential of the long distance transmission circuits, say to 20,000 volts, as soon as experience gained in transmission at 10,000 volts may indicate the practicability of insulating the circuits for the higher potential.

In our memoir of February 6, we recommended 800 volts for the potential in the distributing circuits in the vicinity of the city of Niagara Falls. We were largely guided then, as now, by the consideration that the potential selected should be the highest which may be safely employed at the motors without the interposition of step-down transformers. We assumed, however, at that time that there would be a very large proportion of small motors, as is the case in the hydraulic plant in Geneva, Switzerland, but we are now advised by your engineers that by far the larger part of the power called for in the vicinity of the Falls will be in units of not less than 25 H. P. In such motors, it will generally be safe to employ 2,000 volts."

As I have said, the alternating current system rested, and still rests, upon the transformer, which, having no moving parts, yet enables us at will to transform from low potential to high potential and the reverse, utilizing extremely high, and therefore economical, potentials for transmitting power over long distances while employing moderate and easily handled potentials, both in the dynamos which produce the electricity, and in the motors and lamps which utilize it in markets perhaps many miles distant.

The transformer of Gaulard, which was adapted to constant

current circuits, was brought to the United States by Westinghouse, and was there primarily developed by Stanley and Shallenberger, who early perceived the much greater usefulness of closely regulating transformers adapted to constant potential circuits, and turned their efforts in that direction.

The polyphase motor, as invented by Tesla, occupied no such place in practical engineering work in 1893 as it does to-day, and the same is true of the rotary converter. Tesla and Scott in America, and Dobrovolski in Berlin, had been gradually improving the motor until at the time named it was really a practical and successful machine under certain conditions, but it had not been widely introduced into commercial use, and the enthusiastic hopes aroused when the Tesla invention was first announced in 1888, had not been realized by the public, nor were its possibilities and limitations realized even by electrical engineers, except those who were actually in touch with the work of experimental development.

That the Cataract Construction Company displayed courage as well as good judgment in adopting alternating currents in 1893, and that the subject of alternating current motors was little understood by engineers outside of certain factories at that time is well illustrated by the fact that one of the consulting engineers, of the Cataract Construction Company in a paper on "The Electric Transmission of Power from Niagara," read before the British Institution of Electrical Engineers, November 9, 1893, attaches great weight to the alleged possibility of converting continuous current motors into synchronous alternating current motors by the addition of rings. On page 503 of the Journal of that society he says:

"In concluding my remarks upon low frequency I must again repeat that, from a purely practical and commercial point of view, one of the great advantages lies in the fact that for any special purpose for which a motor is required any ordinary direct current motor may be altered so as to act as a synchronizing alternating motor at a very small expenditure of time and money."

The author apparently had in mind the use of an extremely low frequency, but the fact that he seriously believed in the possibility of converting into commercially effective alternating current motors the general run of continuous current motors is enough to indicate the vague ideas then generally prevalent with regard to alternating current motors.

As regards rotary converters, the function of which is the conversion of alternating currents to continuous currents, thus

rendering available for electrolytic work and for operation of continuous current motors power transmitted in the form of alternating currents, even less was generally known. Schuckert exhibited small machines of this character at the Frankfort exposition in 1890, and in America, Bradley and others had been engaged with more or less success in developing commutating machines of various types. During the autumn of 1892, the Westinghouse Company invited the Cataract Construction Company to examine two 150 H. P. converters and on January 19, 1893, Dr. Coleman Sellers and the late Prof. Henry A. Rowland carefully tested these machines in Pittsburg. The machines were simply four-pole, continuous current, 500-volt, generators fitted with ring collectors. Continuous current at 500 volts was delivered to the first machine, which, operating as a converter, delivered alternating current at 25 cycles per second to a second machine, which, in turn, operating as a converter, delivered a continuous current through a non-inductive resistance. The energy supplied to the first machine and the energy delivered by the second machine were measured and compared, the difference representing the sum of the losses in the two machines. The approximate efficiency of each machine was calculated by dividing the output of the second machine by input of first machine and extracting the square root of the quotient. The efficiency thus obtained for various outputs of the second machine was as follows:

Output of second converter.	Approx. Efficiency of each converter.
20,560 watts	78.9%
57,370 "	90.%
117,970 "	91.5%

These results will compare favorably with those that are now obtained in machines of similar output.

In the autumn of 1892, as Electrical Engineer of the Westinghouse Company and in co-operation with Albert Schmid, O. B. Shallenberger, Charles F. Scott and B. G. Lamme, I planned an organization of electrical apparatus to be exhibited at the World's Fair in Chicago the following year for the purpose of illustrating the possibilities of electric power transmission. The apparatus was constructed and was shown in operation in Chicago from May to November, 1893. Figure 1, which is photo-

graphically reproduced from a descriptive publication which I prepared at that time, shows that this exhibit comprised every essential feature which is to-day utilized by the plant of the

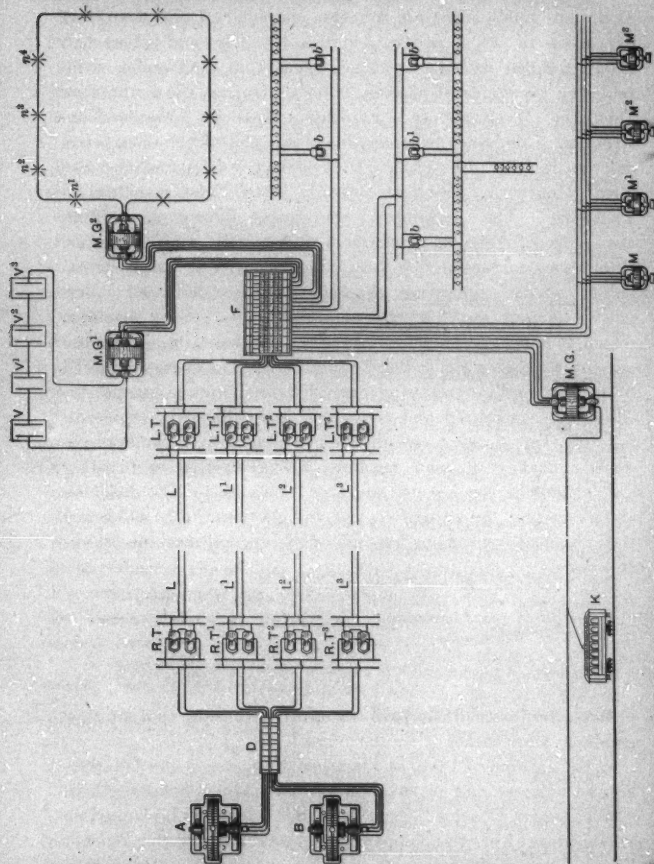


FIG. 1.

Niagara Falls Power Company except the two-phase three-phase connection of the transformers. In the diagram, A and B are alternators; D the power-house switchboard; R.T, R.T', etc., rais-

ing transformers; L, L' , etc., transmission circuits; LT, LT' , etc., step-down transformers; F the distributing switchboard in a sub-station; MG the motor generator or converter receiving alternating current and delivering continuous current for the operation of a street railway; MG' , and MG^2 converters delivering continuous current, respectively, to electrolytic plants and to direct current arc lamps, MM' , etc., polyphase alternating current motors, and bb' , etc., step-down transformers supplying incandescent lamps. In the plant exhibited at Chicago, one 375 k.w. two-phase alternator, one 375 k.w. converter delivering continuous current at 550 volts, one 60 H. P. synchronous motor and a number of smaller machines, including induction motors up to about 15 H. P., were shown.

The frequency was 30 cycles per second, the transmission potential 10,000 volts. A 60-H. P. direct current motor using current from the rotary converter was used to drive an Ingersoll-Sargent air compressor. The 60-H. P. synchronous motor was shown in operation. Incandescent lamps were supplied through transformers and arc lamps by continuous current obtained from a rotary converter.

I deem it proper to make this record in this place not only as a matter of justice to my associates and myself who did much work from 1888 to 1893 in evolving the system adopted at Niagara, but also to establish a fact which is of interest to the INSTITUTE, viz.: that while the Niagara plant embodies the ideas of many men, British and Continental as well as American, the evolution and development of each of the important parts of the system as used at Niagara and the aggregation of these parts into a working plant, accurately adjusted, easily controlled and delivering power to-day for a multiplicity of purposes in Western New York was American, as the far-sighted business enterprise which invested very large capital in a project depending for success upon many factors not tested by experience was also American.

In the descriptive memoir of February, 1893, from which I have above quoted, the application of the system proposed to a territory already occupied by competing steam-driven plants was pointed out as follows:

"Your two-phase alternating current, delivered at high potential at the northern boundary of the city, must be reduced by transformers to a potential that may be safely carried on local

distributing circuits. Your company, or the company to which you will sell current delivered in Buffalo, will desire to make a proposal to the city looking to the substitution of motors for the pumping engines now in use for this purpose. The system offers the two-phase synchronous motors of large capacity—probably of capacity corresponding with that of the engines now installed. These machines will be self-starting, and, using ring collectors in place of commutators, their construction is such as will make maintenance a minimum.

"You will also desire to supply power for the operation of the street railway systems of the city. Our system makes it possible to approach the street railway companies with alternative propositions; first, to furnish motors to drive generators in place of the engines now in use; second, to substitute revolving transformers for both engines and generators; that is to say, to put in place of one engine and one generator, a single machine operating at an efficiency of from 92 per cent. to 95 per cent., depending upon its capacity. The entire steam and electric plant now installed can be held in reserve or sold.

"As regards the arc lighting of the city, you can also make alternative propositions; first, to substitute synchronous motors for engines now in use; second, to install rotary transformers, making a total change in the arc lighting system. In all probability the first of these will be the practicable method at the present time; but the direct and economical method of using the energy of your water power to supply arc lights in Buffalo will ultimately involve a total change of system, and the abandonment of the arc lighting apparatus now used.

For incandescent lighting, the system also offers alternative methods; first, the substitution of synchronous motors for engines; second, a change of system, and the use of large transformers reducing potential from local primary distributing circuits to 50 or 100 volts in secondary circuits. While it may be necessary for a time, owing to the fact that several different interests are concerned, to use the electric energy transmitted from the Falls to supply motors driving existing electric generating apparatus, the system which we have laid out looks to the future, and will lend itself at any time when commercial considerations may permit, to a broad gauge solution of the problem of utilizing the energy of Niagara Falls to supply power and light to the city of Buffalo in the most direct, efficient and satisfactory manner."

The high potential current now actually delivered to transformers in the terminal house near the northern boundary of Buffalo is three-phase and not two-phase as anticipated in the memoir referred to. The change, which of course implied a very marked reduction in cost of transmitting and distributing circuits, was made possible a few months later by the inven-

tion of the two-phase three-phase connection of step-up transformers, without departing from the use of two-phase alternators.

A considerable number of synchronous motors are to-day in use in Buffalo, but they are three-phase and not two-phase motors. The street railway systems of the city are operated by power supplied through converting machinery as described in the memoir.

The arc lighting of the city is accomplished at present by the first of the two alternative methods outlined in the memoir, viz.: the use of synchronous motors in place of engines.

Incandescent lighting in Buffalo is supplied with power in large part by synchronous motors driving constant potential, 60-cycle, two-phase alternators, and, to a less extent, by direct current obtained from rotary converters.

IV. THE FIRST THREE ALTERNATORS AS PLANNED AND CONSTRUCTED.

The general mechanical features of the alternators, *i. e.*, the external revolving field with inwardly projecting field poles surrounding a centrally located and stationary armature, were proposed by Prof. Forbes. For a 5,000 h. p. alternator having a vertical shaft and operating at the very high speed of 250 R. P. M., no better form from a mechanical standpoint has ever been produced. The type, however, is not well adapted to a high potential winding nor to the attainment of very close regulation under conditions of high speed and low frequency. Considerations of mechanical safety limit the normal speed of the periphery of the revolving field to something less than two miles a minute, and when the necessary thickness of ring and length of field pole are subtracted from the radius thus fixed, the limiting diameter of the armature comes out at something like nine feet. A frequency of 25 cycles per second implies 12 poles, and the armature reaction is necessarily so powerful as to render impossible the attainment of 6% or 8% regulation as is now common in slow speed alternators of output comparable to that of the Niagara machines. The small diameter of the armature also limits the space available for insulation and so limits the potential for which the machine can be wisely wound. As the art stands today, a distributed or bar winding for 5,000 volts or an open slot coil winding for 10,000 volts could perhaps be adopted in a machine of this type and size,

without unduly reducing the factor of safety in commercial operation, but these figures cannot be attained without reducing the factor of safety below the point attained in the 2200-volt machines now in use.

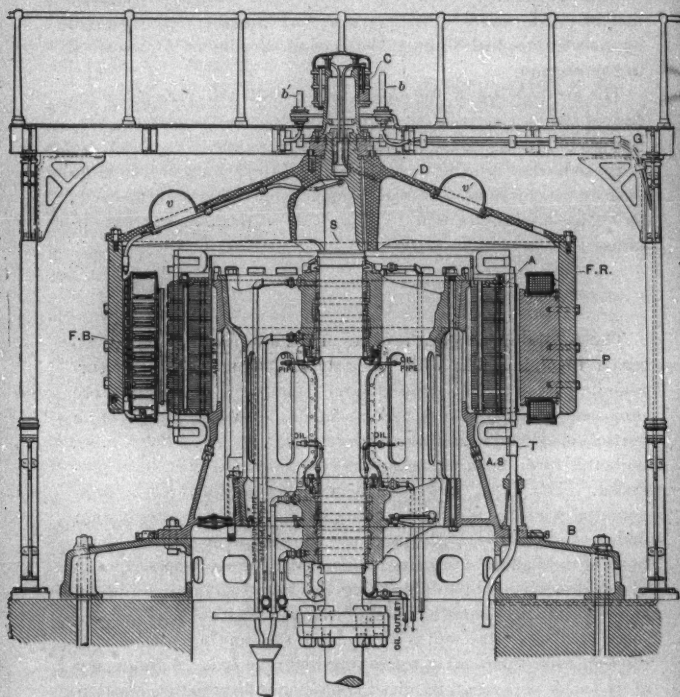


FIG. 2.

When it was decided to wind the Niagara alternators for a potential of 2,000 to 2,400 volts, it was expected that a very large part of their output would be utilized by alternating current motors located within two miles of the power house. This potential, therefore, was chosen with reference not only to a high factor of safety in the insulation of the alternator armatures but also with

reference to the insulation of cables and motors of 25 H. P. and upward, which the company expected to supply without the interposition of step-down transformers. For the conditions of the commercial demand then expected, I believe no better potential could have been chosen.

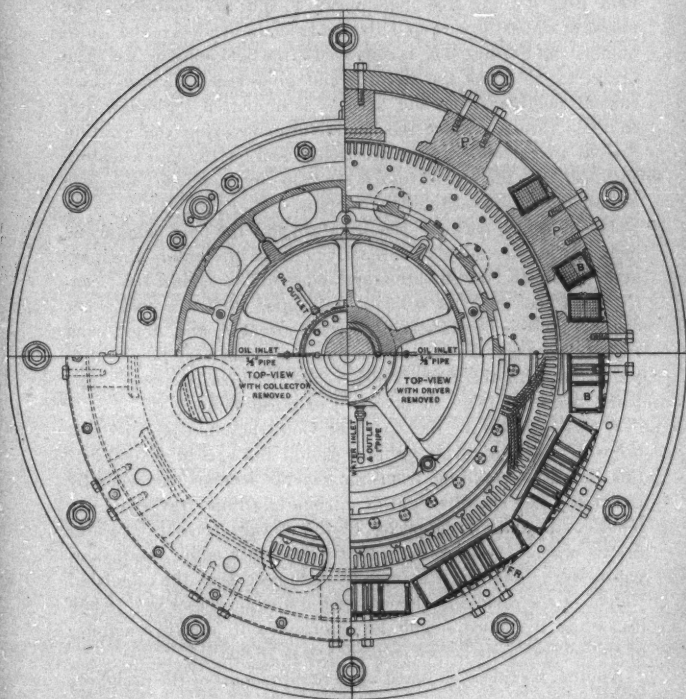


FIG. 3.

Figures 2 and 3 showing vertical and horizontal sections of the alternator, illustrate the construction of the first three machines.

Referring to the vertical section through center line of shaft shown in Fig. 2, A is the stationary armature, secured in place by the armature support A s, which in turn rests upon the bed plate B.

One of the four terminals at which the current from the armature is delivered to the cables leading to the switchboard is shown at T. Of course since the armature is stationary, no ring collectors or brushes for the alternating current are needed. The revolving element consists of the shaft, *s*, carrying the driver, *D*, the field ring, *F R*, the steel pole pieces, *P*, and the collector, *C*, by means of which the current delivered from the exciters to the brushholders and brushes, *b b'*, is conveyed to the field bobbins, *F B*. The bridge which spans the machine and gives access to the direct current collector rings and brushes is supported by hollow iron columns through which the conductors conveying the exciting current are carried. In the horizontal section through armature and field, *A* is the armature, *F R* the field ring *P*, *P'*, etc., the pole pieces, and *B*, *B'*, etc., the field bobbins.

The clearance between the armature and the field poles is one inch. It is interesting to note that in these alternators the magnetic attraction between armature and field acts against the "centrifugal force" and not with it. Of course when the field is not charged there is no attraction between armature and field; even with full charge the magnetic attraction is not very powerful as compared with the force which tends to burst the ring. The point, therefore, is not of any great practical value.

It was specified by the Cataract Construction Company that the weight of the revolving part should not exceed 80,000 lbs., this limitation resulting from the general arrangement whereby practically the entire weight of turbine shaft and revolving element of alternator is supported by the upward pressure of water in the wheel case. As showing the care with which these alternators were designed, it is interesting to note that the calculated weight of the revolving element of the first alternator was 78,958 lbs., while the actual weight, as determined by careful weighing of the several parts before shipment, was 78,600 lbs.

Another specification based upon requirements of the designers of the hydraulic machinery and having reference to speed regulation provided that "the revolving part is to have a fly-wheel effect which when measured by the pounds times the feet per second squared shall be over 1,100,000,000." The calculated fly-wheel effect obtained for each of the first three alternators is 1,274,000,000.

The Field Ring. A serious limitation in designing the alternators was imposed by the high speed adopted, which had been

chosen apparently with reference to the design of the turbines and without full consideration of the design of the alternators. The normal speed specified was 250 R. P. M., but the possible run-away speed at which the alternators must be capable of revolving without danger of bursting the ring was fixed at 400 revolutions per minute. The calculated maximum strain in the ring at 250 R. P. M. is 5,052 pounds per square inch of section, the elastic limit and ultimate tensile strength of the material used being, respectively, about 50,000 and 82,000 pounds per square inch. At a speed of 400 R. P. M. the strains would approximate 12,500 pounds per square inch—*i. e.*, the factor of safety would still be 4. Any increase in diameter would of course increase peripheral speed, and as it was deemed unwise to work under any conditions with a factor of safety less than 4, the outside diameter of the alternator was fixed at 11 feet 7 $\frac{1}{8}$ inches. The peripheral speed at 250 R. P. M. is therefore about 9,300 feet per minute.

When the first drawings of the Niagara alternators were under way it was not known, at least to the writer and his associates of the engineering staff of the Westinghouse Company, that the magnetic permeability of nickel steel was sufficiently high to justify its use in the construction of the field rings. The specification of the engineers of the Cataract Construction Company, dated August 23, 1893, and covering an alternator similar in general mechanical form to that finally adopted referring to the field ring, called for physical characteristics as follows:

"It must also have a tensile strength of not over 56,000 or under 50,000 lbs. per square inch, with an elongation of at least 30% between lines on specimen, the distance between lines being not less than twelve times the thickness of the specimen."

At the time when the first tenders were submitted to the Cataract Construction Company the magnetic qualities of various nickel steel alloys obtained from the Bethlehem Iron Company were undergoing investigation at Pittsburg, and before the contract was placed by the Cataract Construction Company it had been ascertained that nickel steel containing about 3 $\frac{1}{2}$ % nickel possessed extremely high permeability in conjunction with great strength and ductility. The Westinghouse Company, therefore, recommended the substitution of the use of nickel steel field rings, and although the change involved an increase of more than 20% in the cost of the alternators, it is interesting to observe, as indicating the thorough-going manner in which the Cataract

Construction Company carried out its work, that the better material was adopted without a moment's hesitation, notwithstanding its high cost.

The rings of the first ten alternators were forged at the works of the Bethlehem Iron Company, South Bethlehem, Pa. Briefly, the process is as follows:

A nickel steel ingot, 54" in diameter at the bottom, 197" long and weighing about 120,000 lbs., is cast solid and compressed by hydraulic pressure when fluid and during solidification. A block of the required weight is then cut from the ingot and a hole about 15" in diameter is bored through its longitudinal axis. The cylinder thus formed is brought to a forging heat and expanded on a mandril under a 14,000-ton hydraulic press. After forging, the ring is carefully treated, to obtain the physical qualities desired, and is then bored and turned. Samples taken from the edges of the ring before it was turned to its final proportions were tested for ultimate tensile strength, elastic limit and elongation, with the following results:

Sample number.	Tensile strength measured in lbs. per sq. inch.	Elastic limit measured in lbs. per sq. inch.	Elongation in a" measured in percentage of original length.
1	82,915	53,560	27.05
2	81,110	47,230	25.75
3	82,140	49,280	22.5

Samples similarly obtained were used to determine permeability. These samples were shaped into the form of cylindrical bars $\frac{3}{4}$ " in diameter and $7\frac{1}{8}$ " long, the Thompson form of permeameter being used.

Three samples were taken from the edge of each ring, as shown in Fig. 3 A. It will be noted that the axis of two of these samples is parallel to a tangent to the ring while the axis of the third is at right angles to that of the others.

A very interesting measurement of the permeability of the field ring, was made by magnetizing an entire ring by passing a known current through a coil wound about the ring, varying this known current in measured time and determining the resulting magnetization by measurement of the E. M. F. induced in a second coil, also wound about the ring. The E. M. F. induced in the second coil depends upon the number

of turns and the change in the induction through the coil in a given time. Thus if 1,000 lines of induction are taken from the coil in one-tenth of a second a certain electromotive force will be produced. If there is a continuous change of say 1,000 lines each one-tenth of a second for a certain length of time there will be a uniform electromotive force induced during this time. If a given change in induction be made in half the time, the electromotive force produced is twice as great during the shorter period. The ordinary procedure in laboratory measurements of permeability by this method is to wind a ring a few inches in diameter

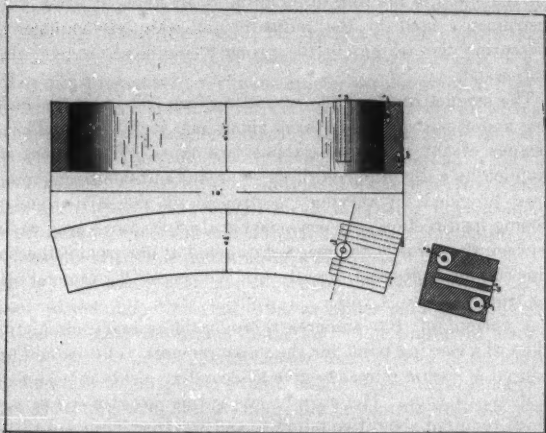


FIG. 3 A.

with two coils, to produce very sudden changes in a magnetizing current through the first coil and to determine the resulting electromotive force in the second coil by means of a delicate ballistic galvanometer which is adapted for measuring the sudden impulse in the secondary circuit.

The length of time required for making definite changes in the magnetization of a ring 11 ft. in diameter and weighing 27,000 lbs. is so great that the ballistic method of measuring is impracticable. The method adopted after several were considered was to change the magnetizing current slowly and at such a rate as to produce a

fairly uniform rate of change in the magnetization of the ring. This produces a uniform electromotive force in the secondary circuit which can be measured by an ordinary voltmeter. The measurement of the electromotive force determines the number of lines of induction added to or subtracted from the ring per second, and this multiplied by the time in seconds determines the total change in induction during a test. The ring was magnetized strongly in one direction, and the current was then reduced, reversed and increased in strength until the ring was again magnetized to the original strength, but in the opposite direction. The total change in induction during the test was therefore twice the induction in the ring in its initial or its final condition. The instruments used in the measurement were an ammeter for measuring the current in the primary circuit, a voltmeter and a stop-watch.

The magnetizing coil was wound uniformly around the entire ring and consisted of 448 turns about one inch apart. The resistance of the circuit was about two ohms. The current was supplied by a direct current generator, and suitable arrangements were provided for varying the strength of the current and reversing its direction. A secondary coil of 30 turns was wound between the turns of the magnetizing coil at one part of the ring. This coil was connected directly to a Weston milli-voltmeter reading from .0001 to .1 volt.

A current of 100 amperes through the primary circuit was taken as a starting point for the measurements. The current was reduced at such a rate as to give a secondary electromotive force of about .04 volts. The current was at this rate reduced to zero, which required about two minutes, and was then increased to 100 amperes in a reverse direction. The change of induction per second required for giving .04 volt multiplied by the number of seconds between the positive and the negative magnetization gives the total change in induction during the test, which is twice the induction corresponding to 100 amperes. Inductions corresponding to different magnetizations could be determined by similar measurements with other current strengths. In the tests, however, readings were made upon the ammeter and voltmeter simultaneously at intervals of about ten seconds, and intermediate points between the two extremes were determined for plotting in a curve. It was very difficult to keep the secondary electromotive force exactly constant, but the result of a number of tests

showed that no great error was introduced on this account, and that the average results were practically correct.

The permeability to be determined is the relation between the induction in the ring, measured by means of the voltmeter and the stop-watch, and the magnetizing force required to produce it, which is determined by the measurement on the ammeter multiplied by the number of turns. The electromotive force in the secondary coil when the induction through the coil is varying at a uniform rate is proportional to the number of turns, and the change in the number of lines of induction per second. The total change in induction during such a test is therefore found by determining the change per second by the voltmeter, and multiplying this by the time. The results of the measurement, plotted in the form of a BH curve, are shown in curve E, Fig. 4.

The measurements by the permeameter are also given in Fig. 4, in which curves A and B are, respectively, BH curves for wrought iron and cast iron, as determined by Hopkinson, using the ballistic method; C is the BH curve of nickel, as determined by Ewing; D the mean BH curve of the samples of nickel steel cut from the edge of the ring of the second Niagara alternator as determined by permeameter method and E the BH curve of the entire ring, as determined by the method above described.

It is to be noted that the curves by the two methods agree closely at low inductions, but differ at higher inductions, the ring method showing the higher induction. The sources of error at high induction in the permeameter due to error in estimating the length of the magnetic circuit, and in the leakage of magnetic lines from the sample near the point of contact with the yoke, tend to account for this discrepancy. The fair agreement between the two methods of measurement is of especial interest, as the measurements in one method are of force and current made by a spring balance and an ammeter, and in the other method measurement of electromotive force, time and current made by a voltmeter, a watch and an ammeter.

Field Poles and Winding.—The field poles are mild open-hearth steel castings. Their permeability is practically equal to that of the field rings. The field winding of the first three alternators as originally planned consisted of copper conductors of rectangular section about equivalent to one No. 0 wire B. and S. gauge. These conductors were covered with the usual cotton insulation and the coils were inclosed in ribbed brass boxes, from which

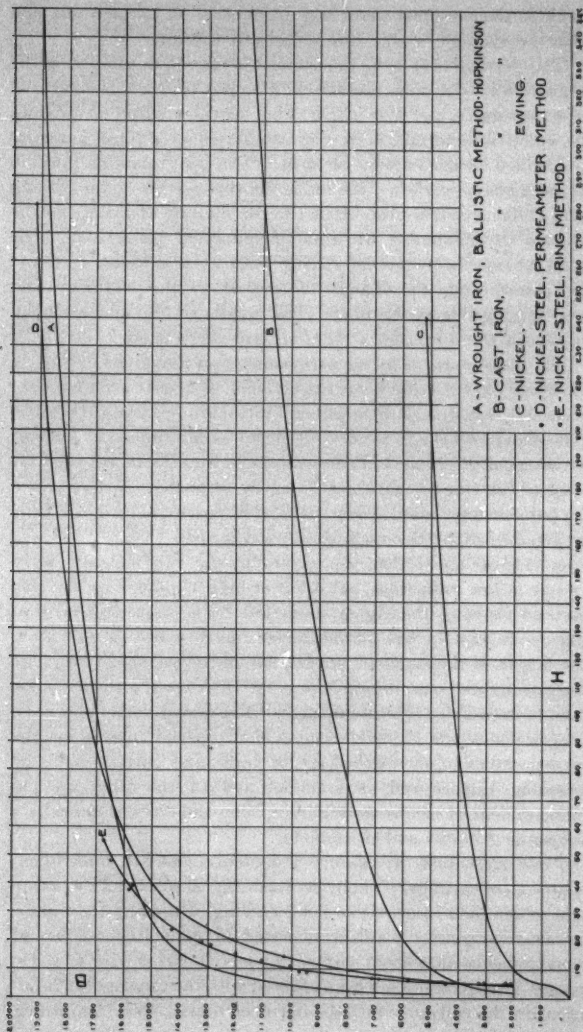


FIG. 4.

they were insulated by sheets of mica with heavy strips along the edges where the coil would otherwise press most heavily against the box. The weight of each pole piece with its bobbin is 2800 lbs.

The bronze collector rings are built upon a separate cylindrical casting placed above the driver and securely fixed to the hub of the latter by heavy screws through a flange at its base. The brush-holder rods are held in place by a heavy iron bracket encircling the casting below the collector rings. This bracket rests upon the bridge which spans the machine and gives access to the collectors, brush-holders and brushes.

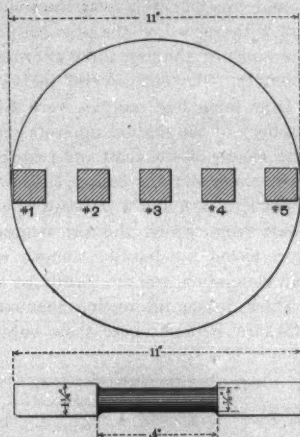


FIG. 5.

Driver.—The field ring is carried by an umbrella-shaped steel casting, to the periphery of which the ring is secured by bolts as shown in the vertical section Fig. 2. The driver is turned on its outside surface and is strengthened by six deep ribs on the inside. The steel used is of excellent quality, samples taken from a casting near the periphery of the first driver, which samples are fairly representative of all the drivers, showing by test a tensile strength of 74,000 lbs. per square inch, an elastic limit exceeding 44,000 lbs. per square inch, an elongation of 30% in three inches,

and a reduction of area of 43%. The surfaces of the fracture where specimens were broken were silky and fine-grained.

Shaft.—The shaft is tapered at its upper end to receive the driver and at its lower end a forged flange 27" in diameter provides means for connection to a similar flange at the top of the turbine shaft. These flanges are held together by eight tapered steel bolts. The diameter of the shaft in the bearings is $12\frac{1}{8}$ inches. It is tapered at the upper end to receive the driver and is also threaded to provide means for securing in place an iron casting which projects above the driver and carries the collector rings. A key-way is cut in the tapered end of the shaft and also in the bearing of the driver which is fitted to it, the driver and shaft being held together by a long, massive steel key. To obtain information with regard to the physical properties of the steel used for the shaft of the first three alternators, they were forged of extra length. An end several inches in length was then cut off and from these five samples were taken, two being cut from the periphery of the shaft at opposite ends of the diameter, one from the center of the shaft and two from points midway between the periphery and the center, as illustrated in Fig. 5, where the numbers 1, 2, 3, 4 and 5 indicate the places in the section of the shaft from which the test samples were taken. These samples were tested for tensile strength, elastic limit, reduction of area and elongation, and the results, as set forth in the following table, show in an interesting manner the fact that solid forged shafts are stronger near their outer surface than elsewhere.

Sample number.	Tensile strength in lbs. per sq. inch.	Elastic limit in lbs. per sq. inch.	Reduction of area in percentage area before test.	Elongation in percentage of length before test.
1	63,000	35,500	53	37.5
2	59,000	29,500	51	38
3	56,000	28,500	37.5	31
4	58,500	31,500	41.5	38
5	62,500	35,000	55.5	35

Bearings.—Babbitt lined bearings are used and provision is made for cooling the bearings by circulation of water through openings in the cast iron bearing boxes. It is interesting to note that the babbitt lined bearings of the alternators have been satisfactory from the start while the bronze guide bearings originally provi-

ded for the shafts connecting the first three turbines with the corresponding alternators gave much trouble and have all been replaced by babbitt lined bearings.

Method of Balancing the Revolving Field.—The method employed in balancing the revolving element of the alternators was devised by Mr. Albert Schmid and is illustrated by Fig. 6.

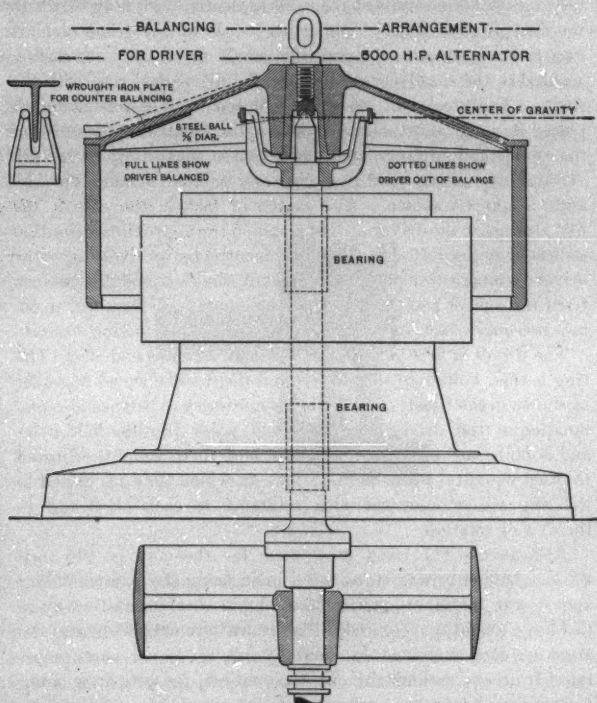


FIG. 6.

A special shaft is placed in the bearings of the machine, and supported at its lower end by a thrust bearing into which oil is pumped at a pressure of about 1,000 lbs. per sq. in. This pressure is sufficient to lift the weight of the revolving parts, and the collars on the shaft are separated from the grooves of the thrust

bearing by a thin layer or film of oil. A small piece of tool steel is set into the upper end of the shaft, a half sphere or cup being cut in the upper surface of this tool steel, in which is placed a tempered steel ball $\frac{3}{8}$ " in diameter. A large eye-bolt with a similar piece of tool steel, having in its lower surface a cup bearing similar to that at the top of the shaft, is secured in the taper bearing of the umbrella-shaped driver, to the periphery of which the field ring is bolted. The entire weight of the driver and the ring is thus supported upon the small steel ball. A casting secured to the shaft serves to rotate the driver and ring with the shaft. The steel ball, as will be noted in the illustration, is placed a very short distance above the centre of gravity of the field and driver, and under these conditions, the driver and ring being free to rock while rotated, a defect in balance is quickly shown. As a matter of fact, in the case of the first alternator the driver at first assumed the approximate position indicated by the dotted lines. This was corrected by rivetting to the driver a wrought iron plate, the weight of this plate and the distance from the axis of rotation being experimentally determined to obtain not only exact static balance but also exact running balance.

The driver is first balanced in this manner independently. The ring is then bolted to the driver, and the two balanced together as shown in the illustration. It is not necessary to balance the combination of the driver, ring and field poles since the field poles and bobbins are separately weighed, and their weights adjusted to exact equality, while the positions in which they are bolted to the ring are symmetrical with reference to each other and to the axis of rotation.

Armature.—The sheet steel used for the core is .015 inch thick. Difficulty was experienced in securing the desired quality and it was found impracticable to obtain absolute uniformity in the large quantity required. To secure circulation of air, the armature core is divided horizontally into six equal parts, separated from one another by one inch spaces, these spaces being maintained by brass spacing strips, whose position is approximately radial to the machine. Each layer of the core consists of eleven segments which are so placed that all joints in each layer are overlapped by the segments of the adjacent layers. The plates are annealed, but in the first three alternators are not japanned.

The laminated ring thus built up to form the armature core is held together by 66 bolts of nickel steel containing a high per-

centage of nickel which renders them practically non-magnetic. These bolts are carefully insulated from the core. The large disks or end-plates at the top and bottom of the armature ring are of brass. At the time of tightening the bolts, the steel plates were pressed closely together by powerful hand presses. The entire ring constituting the armature core when finally built up was turned on the inner surface so as to accurately fit the ribs of the armature support. It was then heated and lowered into place against the flange on the support and in cooling, of course, adjusted itself tightly into place against the ribs. The armature conductors are copper bars $1\frac{1}{2}'' \times \frac{7}{8}''$ in section, the edges of the bars being rounded to a radius of about $\frac{1}{8}''$. Two of these bars are placed in each of the 187 slots around the periphery of the armature core. The conductivity of the bars is above 100%

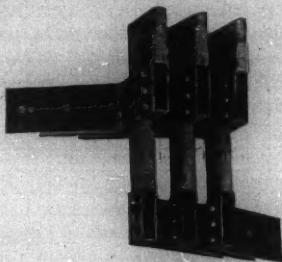


FIG. 7.

by Matthiesen's standard, the actual conductivity in the case of the second alternator being 102.6% by that standard. The bars are encased in mica applied before they are put in place. The insulation is about $\frac{3}{8}''$ thick. The insulation of each bar was tested by connecting one terminal of an alternating potential to the conductor, while the other was connected to a layer of tin-foil wrapped about the tested insulation. The insulation of every bar was required to withstand 15,000 volts, alternating, applied for a few seconds. The completed armatures were tested by the application of 8,000 volts, alternating, for a period of about one minute. The armature bars project above and below the core and connections are made by pieces of copper punched from

large sheets and shaped into proper form by presses and iron molds. These connections are insulated by mica and rubber insulating tape, the former being used only when connectors conveying considerable difference of potential are adjacent to each other. The connectors are secured to the armature bars by three wrought iron bolts the heads of which are countersunk in one side of the split connector, while the nuts are locked by upsetting the projecting ends of the bolts. Finally, the joints are thoroughly soldered. Fig. 7 shows the junction of six armature bars and connectors before they are soldered and insulated. The conductors are so connected as to form two complete circuits, each thoroughly insulated from the other and from the steel core.

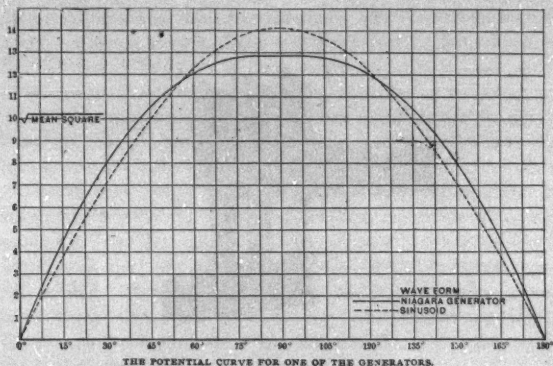


FIG. 8.

Potential Curve During a Half Cycle.—The potential curve of one of the first three alternators during a half cycle, and for purposes of comparison a sine curve, are shown in Fig. 8. The following interesting method was adopted in determining the form of this curve:

The machine was run at a very low speed so that the needle of an ordinary voltmeter connected across the terminals would follow the variations of electro-motive force, increasing to a maximum, decreasing to zero, reversing and increasing to a maximum in the reverse direction. Readings upon the voltmeter were made at regular intervals and the results plotted, thus giving the curve of the machine.

This method of measurement requires a uniform and very slow speed. Variations of one or two per cent in the speed will cause corresponding variations in the electro-motive force. In the test the slow speed was obtained by winding around the field ring a wire rope, which was attached to the shaft of a vertical lathe. The lathe was run at a slow and uniform speed, winding up the rope, which was drawn from the ring, thus revolving the machine. Difficulty was experienced at first in obtaining a uniform speed when heavy iron wire was used instead of the cable finally adopted. The speed was irregular, due to stretching of the wire, as the friction to be overcome was not uniform at the slow speed. The adoption of a steel cable very nearly eliminated the irregular motion. The machine was belted to a direct current motor supplied with current nearly sufficient to cause rotation, and the additional force was supplied by the cable which was able in this way to maintain a uniform speed.

The speed of the ring was about one revolution in ten minutes, giving one alternation in about 50 seconds. The speed of the machine is thus reduced from normal, 250 revolutions, to one-tenth revolution per minute, or in the ratio of 2500 to 1, and the electromotive force of the normal field charge is consequently reduced from 2000 volts to .8 of a volt effective, or a little over one volt maximum. This electromotive force could be reduced as desired by resistance in circuit with the voltmeter. In making the measurements, a voltmeter was placed across each of the circuits and readings were taken at intervals of $2\frac{1}{2}$ seconds, as indicated by a signal. Observations were continued through several minutes, covering a number of cycles. The results were plotted and the successive cycles which should be similar, if all the conditions remained constant and the observations were correctly taken, were superposed and the average adopted as the correct result. Variations in speed and in the time of taking readings, and in the readings themselves, were in this way found to be slight and were eliminated by taking averages. The voltmeter was a Weston milli-voltmeter with the zero of the scale in the middle so that both positive and negative readings could be taken without changing connections.

The wave form of the machine was also calculated directly from the drawings. The calculated and measured curves agreed very closely.

V. THE FIRST THREE ALTERNATORS UNDER TEST AND IN SERVICE.

The manufacturer guaranteed that the total electric and magnetic losses, when delivering 3730 kilowatts, should not exceed $2\frac{1}{2}\%$ of the power required to drive the alternator. Before shipment, therefore, tests were made in the shops at Pittsburg to determine the losses due to magnetization of the armature core, the alternator being supported on a thrust bearing into which oil was pumped at a pressure of 1000 lbs. per square inch to support the weight of the revolving field which was driven by a direct current motor. The fields of the motor were separately excited. The energy delivered to the motor was measured by Weston ammeters and voltmeters previously compared with standards, and simultaneous observations of speed, field charge, potential at terminals of alternator and current delivered to the motor were recorded. These tests were repeated a number of times and satisfactory agreement of results was obtained. The energy required to magnetize the field was accurately measured in the course of full load tests carried out in the power-house where a large rheostat was constructed and used for loading the alternator. The loss due to resistance of the armature conductors was calculated from the measured resistance and the known mean current. No allowance was made for possible eddy currents in armature conductors. The losses and efficiency in the case of the first three alternators thus determined were as follows:

Loss in armature core	42 K. W.
I^2R loss in armature	29.2 K. W.
I^2R loss in field	11.4 "
Total	82.6 "
Kilowatt output	8730 "
Kilowatt input	8818 "
Efficiency	97.82 %

Ventilation.—Much difficulty was encountered in securing proper circulation of air throughout the interior of the machine. When the alternators were designed it was expected that a plenum would be established in the interior of the armature, and that the air would flow radially outward through the armature core. Six holes in the driver were provided for ventilation, and above each of these holes a copper ventilating-hood, opening forward—i. e., in the direction of rotation—was placed.

The space within the armature support is open at the top, no hatches being used between the five radial arms at the top of the bearing support, and as it was at that time deemed inadvisable to reduce the strength of the ring by providing openings through it for radical escape of the air, some difficulty was experienced in establishing satisfactory ventilation. After some experimenting, the position of the hoods on the top of the driver was reversed, with the idea that they would thus act as exhaust or suction blowers to draw the air out of the interior of the machine, and after this change was made, excellent ventilation, except at the top of the armature, was secured, the air being drawn in through the space between the field and armature and the space between field poles, flowing thence inward radially through the armature core and finally escaping through the openings in the driver, the total amount of air thus passing through the machine being not less than 9,000 cu. ft. per minute. At the top of the armature, the cast-iron armature support, being designed for an expected plenum inside, interfered to some extent with the flow of air through the upper ventilating space in the core, as a consequence of which the temperature as measured at the top of the core exceeded the guaranteed limit, viz., 50° C. above surrounding air, by about 10° C. Water cooling devices in the shape of shallow copper boxes applied to the inner surface of the cast iron armature support were added to the first three alternators but in practice they are seldom used as experience has shown that the temperature attained by the machines does not seriously endanger and apparently does not practically injure the insulation used.

Original Field Coils Defective.—As I have stated, the conductors used in winding the field coils originally designed for the first three alternators were covered with cotton insulation. Under test, the temperature of these coils, as determined by thermometer applied to the outside of the shells and as determined by measurement of resistance, was well within the guaranteed limit—i.e., 50° C. above surrounding air; but after the machines had been operated for a time it was found that the exciting current was gradually increasing from week to week and from month to month. Investigation showed that this was caused by excessive heat in the middle of the coils, which was gradually charring the cotton insulation and causing a part of the current to leak across from one layer to another, instead of following the conductor.

The coils which had proved defective were replaced by coils of a new type, in which the conductor is a copper strap $1\frac{3}{16}'' \times 1\frac{1}{8}''$ in section, bent on edge, successive turns being insulated by micanite placed between them as in commutator construction. The edges of the strap conductor are exposed to the air. This type of construction is now extensively used, but I think was first used in these alternators. There are four layers of turns separated from each other by insulated spacing-rods, the whole being enclosed in a metallic case provided with abundant openings for circulation of air. These coils in service under full load rise only 12° C. above surrounding air, as determined by thermometer and by measurement of resistance.

The first alternator was put into commercial service October, 1895, the second alternator following a few months later, and the third beginning its commercial work in 1897. They have been in practically continuous use ever since they were started, being shut down regularly once a week for a few hours, when they are thoroughly cleaned and inspected. Allowing for all stoppages, the use of the first three alternators to date in actual running time is more than equivalent to five years' absolutely continuous use, and in that time there has been no failure in any part of any one of the three alternators which has caused one minute's interruption of service. This excellent record is undoubtedly due in part to the system of inspection and testing adopted, each alternator being thoroughly cleaned once a week, while at intervals of about three months the armatures are subjected to a test potential of 6,000 volts, and any armature bars having insulation which will not withstand this test are removed and replaced by others. This, in my opinion, is the proper manner to take care of electrical machinery. The total cost of maintenance of these alternators since the field coils were replaced has not exceeded 1%, whereas if they were not kept in first-class condition it is not difficult to imagine how accidents might occur, causing much and expensive damage.

VI. ALTERNATORS 4 TO 10.

Alternators 4-10, inclusive, were designed in 1896. The first alternators had been erected, tested and were in commercial service. As compared with the first three alternators, which were designed in 1893, the following differences were introduced:

The thickness of the field rings was increased from $4\frac{7}{8}$ inches to 5 inches. A slight reduction in weight of the shaft connecting turbines and alternator made it possible to increase the weight of the revolving field by about 2,000 lbs. The additional weight was put into the ring as being most effective there, both with respect to strength and flywheel effect. The increased thickness made it possible so to do without reducing the factor of safety in the ring below the standard established for the first three alternators. The heads of the bolts which hold the field poles to the ring were countersunk.

Tests of additional samples of nickel steel having demonstrated that an alloy containing $4\frac{1}{2}\%$ nickel would be satisfactory with respect to permeability and ductility, while superior with respect to ultimate tensile strength and elastic limit, steel containing $4\frac{1}{2}\%$ nickel was used for the rings of the alternators 4-10.

The following table shows results of tests of samples from number of these rings. It is safe to say that no better steel has ever been used in the construction of dynamos.

	Tensile strength lbs per sq. inch.	Elastic limit lbs. per sq. inch.	Elongation in 2" about	Reduction of area.
Specified requirements.....	90,000	45,000	18%	
Obtained in samples repre- senting various rings.				
93,110	55,890	23.75	47.82	
95,510	58,530	18.65	39.29	
98,290	63,150	19.60	42.84	
90,140	51,590	24.30	49.01	
94,600	57,270	23.80	46.18	
92,040	52,150	20.10	35.41	
90,650	50,930	20.50	34.70	
95,740	57,040	23.60	44.64	
96,250	58,060	23.65	45.53	
95,740	55,000	25.05	46.70	
104,030	61,800	20.75	—	
99,200	56,250	22.13	—	
103,290	60,330	20.25	—	
93,710	65,180	21.00	41.31	
93,200	66,720	21.50	41.92	

The permeability of samples from these rings was very close to that of the rings which contained about $3\frac{1}{4}\%$ per cent. nickel as illustrated in Fig. 5.

The winding of the armature was modified with a view to securing an increase in efficiency and closer regulation, the new winding consisting of 334 bars placed in an equal number of slots in place of 374 bars placed in 187 slots.

The clearance between armature and field was reduced from 1 inch to $7/8$ inch.

For the old method of building up the armature core, which involved the use of nickel steel bolts, the now generally adopted method of dove-tailing the sheet steel plates of the armature into grooves on the outer periphery of the cast-iron support and holding the complete core in place by end plates, secured by means of circular keys, was adopted. This improvement in the method of manufacture in connection with the more uniform quality of steel obtainable, the painting of the plates by an insulating varnish and the more accurate punching and fitting of the plates, which made it unnecessary to do as much filing of the slots as was required in the case of the first three alternators, resulted in a reduction of the core loss amounting to about 15 kilowatts. Instead of six horizontal one inch ventilating spaces through the armature core, twelve spaces of about $\frac{1}{2}$ inch were provided and the openings through the cast iron armature support were extended in such a way as to permit more effective ventilation in the upper part of the core.

As regards shaft and bearings, hollow forged nickel steel shafts were substituted for the solid shafts used in the first three alternators and the iron shell surrounding the babbit-lined bronze bearings was cored out to permit circulation of water and was not split, this improvement making it absolutely impossible for the oil and water used in cooling and lubricating the bearings to get mixed to the detriment of the oil.

During the period which had elapsed since the first alternators were designed, the manufacture of hollow forged shafting had been brought to a high degree of perfection by the Bethlehem Iron Company and in line with the policy of the Cataract Construction Company, which aimed to secure nothing less than the best in material and design, they were adopted for the new alternators. The use of the hollow forged shaft had reference also to the use of a very ingenious torsion dynamometer designed by Dr. Coleman Sellers and intended to measure the force delivered to the alternator by the turbine shaft. The use of the hollow forged shaft made it possible to dispense with the bridge over the alternator by placing the collector rings below the armature and carrying the exciting current to the field through conductors placed inside the shaft. This arrangement was not adopted for alternators 4-10, however, as the change in external appearance caused by removing the bridges would be radical and it was thought desirable to maintain in all alternators installed in the same power-house general uniformity of design.

The reduction in losses, particularly in core loss, implied of course a reduction in heat to be dissipated, and as by reason of increased thickness the rings were stronger than those used for the first three alternators, it was thought safe to provide openings for ventilation along the upper edge of the ring where it is secured by bolts to the driver. It was decided, therefore, to omit the ventilating hoods from the new alternators, but as this omission involved some uncertainty as to the ability of the machine to operate within the desired temperature limit, provision was made for cooling the interior of the machine by water circulating through the cast-iron armature support. When the machines were completed and tested, however, it was found that they would operate within the required temperature limit without the use of water.

VII. PERFORMANCE OF ALTERNATORS 4-10 UNDER TEST AND IN SERVICE.

Efficiency.—The method adopted for determining the efficiency of alternators 4-10 was the same as for the first three alternators, *i. e.*, the core loss was determined by measuring the increase of power required to drive the alternator with charged field as compared with the power required to drive it at the same speed with no field charge; the $I^2 R$ loss in armature was calculated from the mean current and the measured resistance; and the $I^2 R$ loss in field was also calculated from measured current and resistance. To the core loss at no load, 20% was added to cover increase due to distortion of magnetic field in the armature under full load and for partial loads the measured core loss at no load was increased proportionately. The following tabulated statement of electric efficiencies of alternators 4, 5, 6, 7 and 8, is an exhibit which should be gratifying to the manufacturer, to the purchaser and to the members of the INSTITUTE, as showing what electrical engineering science in America was able to accomplish in 1896, within twelve years of the time when alternating current electrical machinery first appeared within the horizon of practical application.

Total amps. at 2400 volts.	Elec. Eff. Alt. No. 4.	Elec. Eff. Alt. No. 5.	Elec. Eff. Alt. No. 6.	Elec. Eff. Alt. No. 7.	Elec. Eff. Alt. No. 8.
400 amps.	96.20 per cent.	95.99 per cent.	96.85 per cent.	96.4 per cent.	96.2 per cent.
800 "	97.65 "	97.6 "	98.1 "	97.78 "	97.66 "
1200 "	98.00 "	97.96 "	98.25 "	98.11 "	98.02 "
1600 "	98.1 "	98.07 "	98.32 "	98.18 "	98.10 "
2000 "	98.12 "	98.06 "	98.33 "	98.15 "	98.07 "

The first three alternators designed in 1893 and 1894 were to all intents and purposes as effective as the fourth and succeeding alternators, except that methods of manufacture were not then sufficiently perfected as regards treatment and handling of armature cores to permit reduction of the core losses within the limit established by the succeeding alternators, the result being that the efficiency of the first three alternators was about .3 of one per cent. lower than the efficiency of the others as shown in the table; in other words, the electrical full load efficiency of the first three alternators was about 97.8% while the electrical efficiency of the last seven alternators averages fully 98.1%. The mechanical friction, *i. e.*, air friction and bearing friction, amounts to 1.1%. The net commercial efficiency of the first three alternators is, therefore, 96.7%, and that of the last seven alternators, 97%. Surely, results such as these, considered in connection with the excellent record of these machines in practical operation, leave no ground for belief that the designers of 5,000 H. P. alternators are in any way less certain to attain desired results than the designers of large engines, or turbines or bridges.

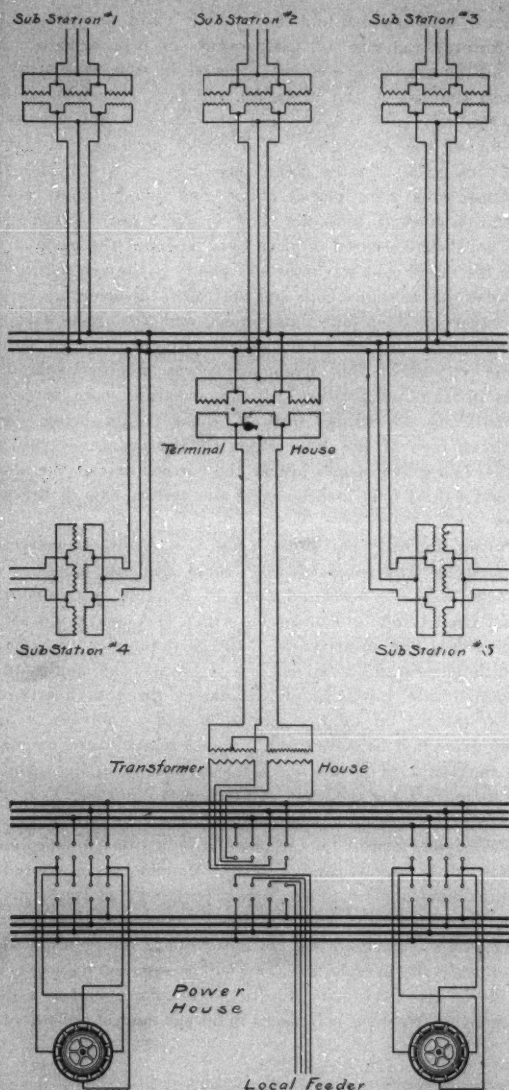
Temperature.—In determining the temperature, thermometers were applied to the outside surfaces of the armature, as was done in testing the first three alternators, and in addition to this the much more delicate and accurate method of determining rise of temperature by increase in resistance of exploring coils placed in the ventilating slots of the armature core was adopted. The exploring coils were made of wire .0025 inch in diameter, which was furnished by a dealer as platinum wire. Our determination of the coefficient of resistance in rise of temperature, however, showed that the wire was not pure platinum. The coefficient of these exploring coils was determined by measurements of resistance at various temperatures ranging from 10° C. to 85° C., while coils were immersed in an oil bath. A series of measurements was made beginning at 85° C. and reducing the temperature to 10° C., from which point the temperature was again gradually raised to 85° C. During these measurements, the oil was stirred and the results obtained were gratifying, the maximum variation in the coefficient, as determined by a number of successive measurements, being less than 1%.

The coefficients being thus determined, the lengths of the coils were so adjusted that an increase of .1 of an ohm in the resistance

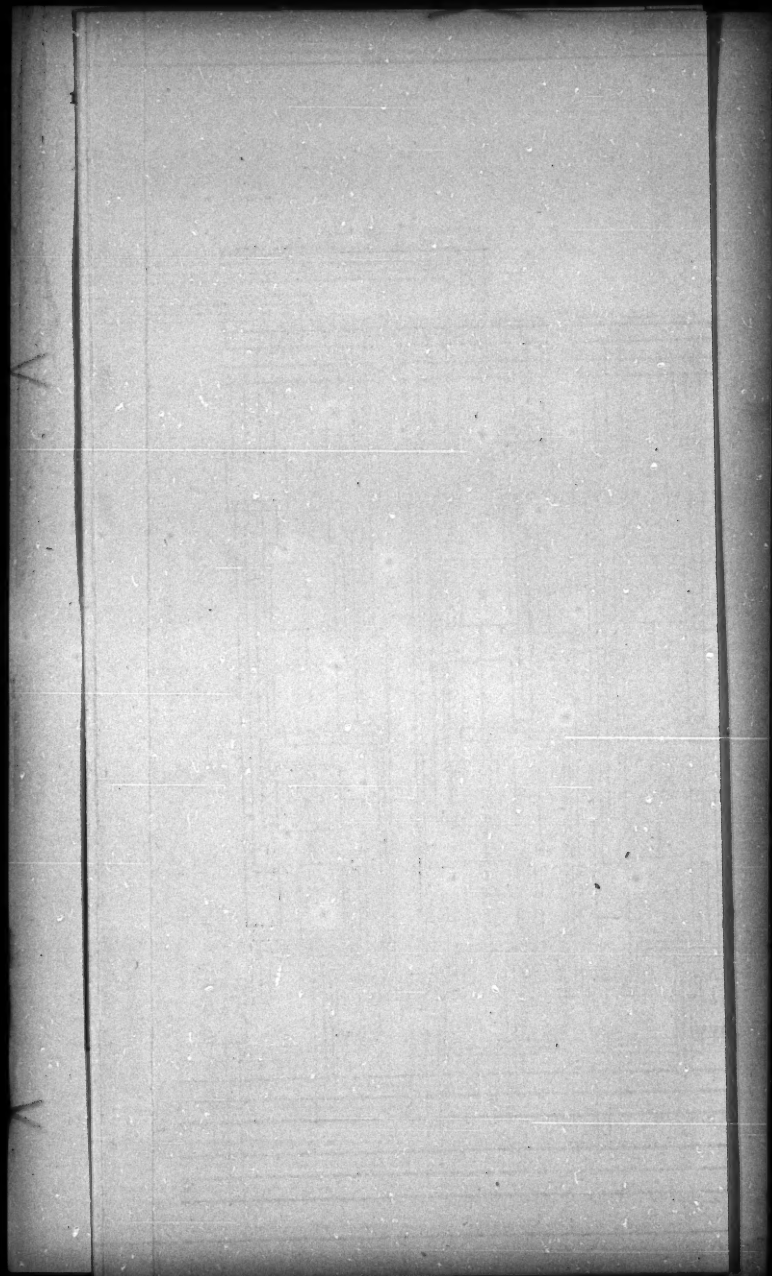
of a coil corresponded to a change of 1° C. in temperature. In determining the rise of temperature of the armature core, one of the exploring coils was located in the ventilating slot nearest the top of the armature, one in a slot about half way between top and bottom, and one in the slot nearest the bottom of the armature. The exploring coils were wound on a thin piece of mica about one inch in width and three of these coils were placed about two inches apart and secured to a piece of fibre one inch in width and 10 inches long. The coils were secured in place by a tape and the piece of fibre with the taped coils was inserted radially in the ventilating slots. Between the resistance coils and the iron of the armature core but one layer of linen tape intervened, and the coils were thus brought into intimate contact with the iron and the armature.

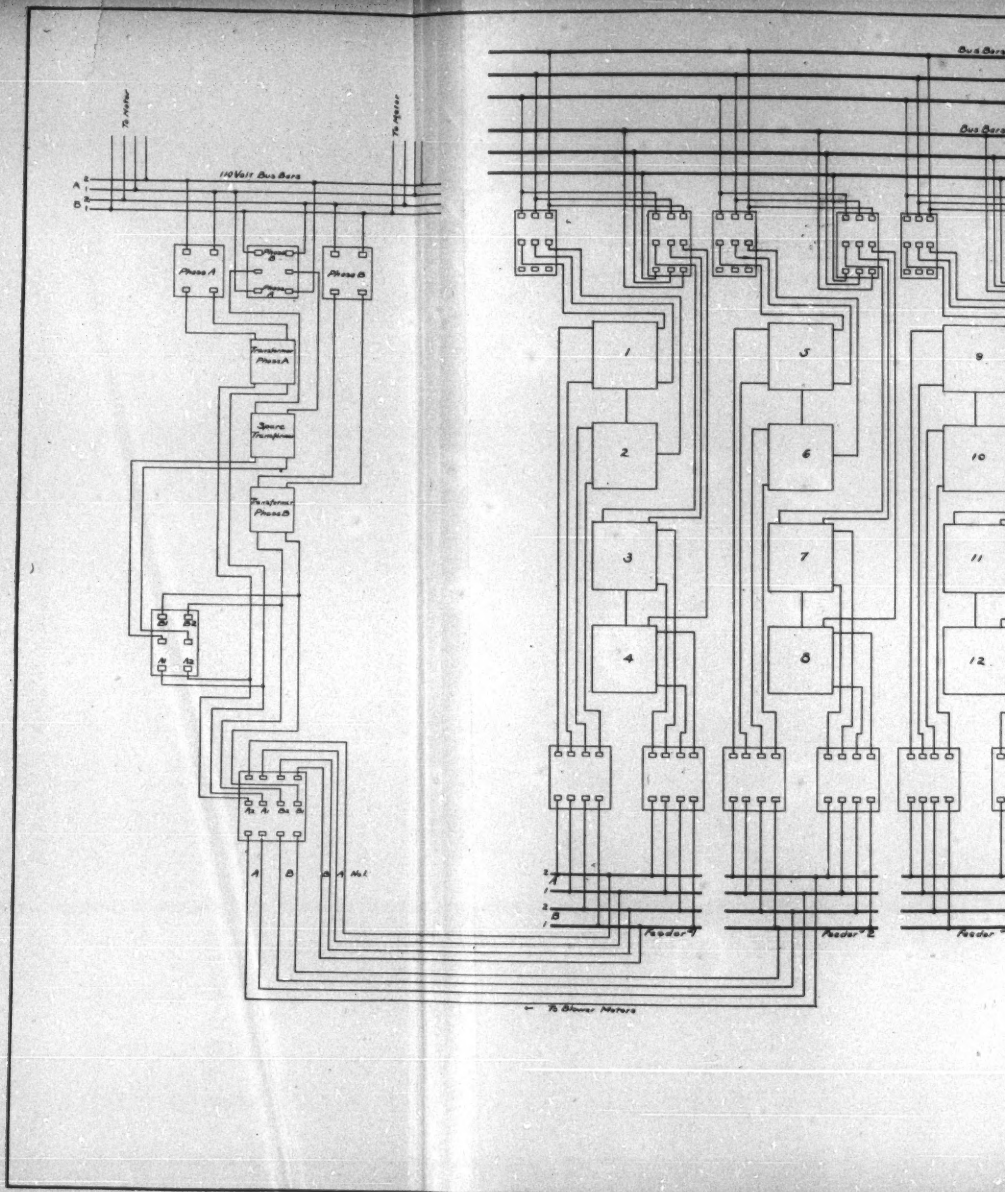
The purpose of this arrangement was to observe the differences in the temperature of the armature core at several points along a radius, one of these points being located within an inch of the inner edges of the armature conductors, another being two inches nearer the vertical axis of the alternator, and a third four inches nearer the vertical axis of the alternator.

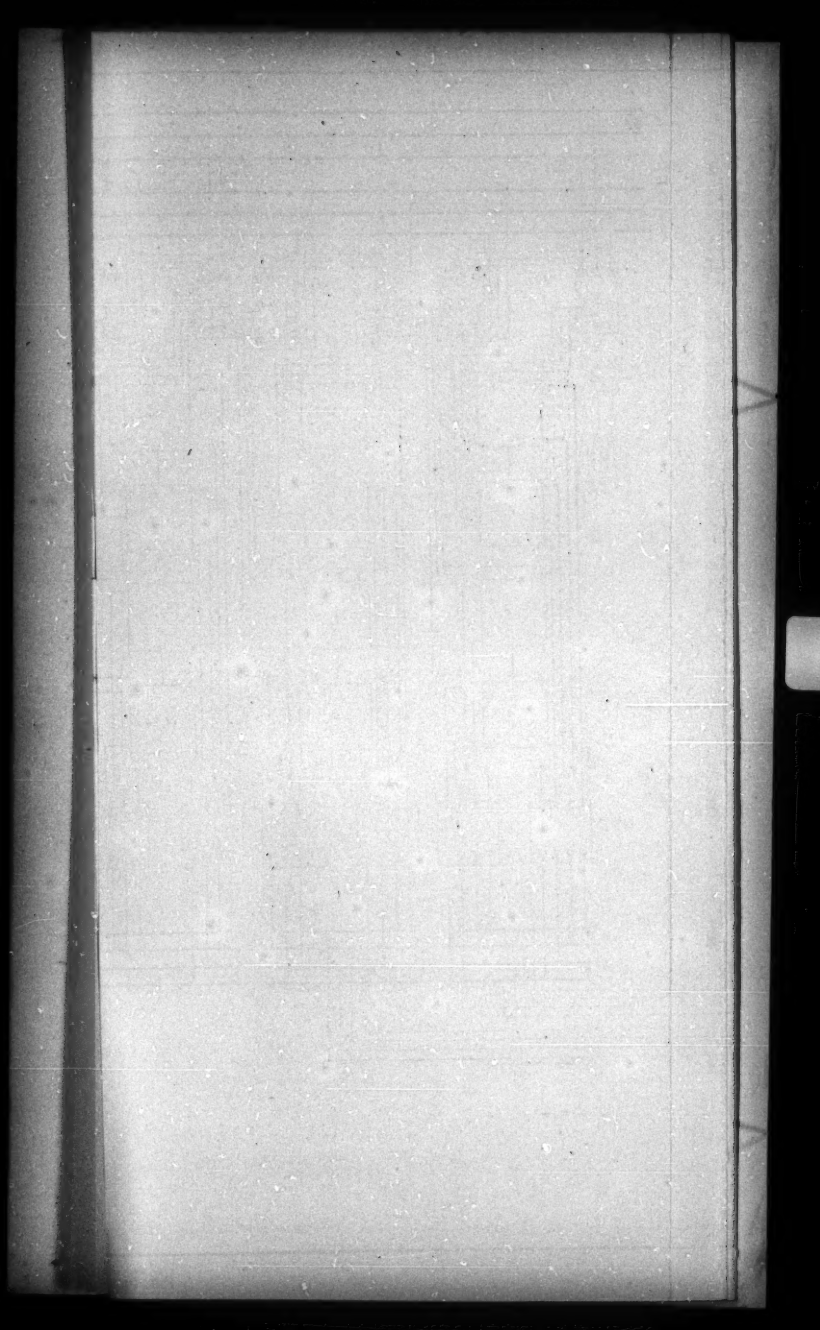
During the early part of each test, *i. e.*, while the increase of temperature was comparatively rapid, the resistance of the exploring coils was measured every 15 minutes by means of an Elliott Bros. bridge in connection with a D'Arsonval mirror galvanometer. The sensitiveness of the galvanometer was such that the difference in the resistance of a coil due to the maximum rise of temperature produced an equivalent throw of nearly 5,000 feet in the ray of light on the scale and a movement of $\frac{1}{8}$ of an inch could be easily read. As the temperature, and therefore the resistance of the coil, increased, the ray of light could be seen to move along the scale at a rate approximating 25 feet per minute. The measurements obtained were very satisfactory, the exploring coils nearest the armature conductors showing temperatures a few degrees higher than temperatures measured by thermometers applied to the outer periphery of the armature core. They also indicated that even the exploring coils nearest the armature conductors did not measure the temperature of the hottest parts of the armature. This will be apparent upon examination of Fig. 12, showing graphically the rise of temperature as determined by an exploring coil placed in the slot nearest the top of the



Local Feeder
FIG. 9.







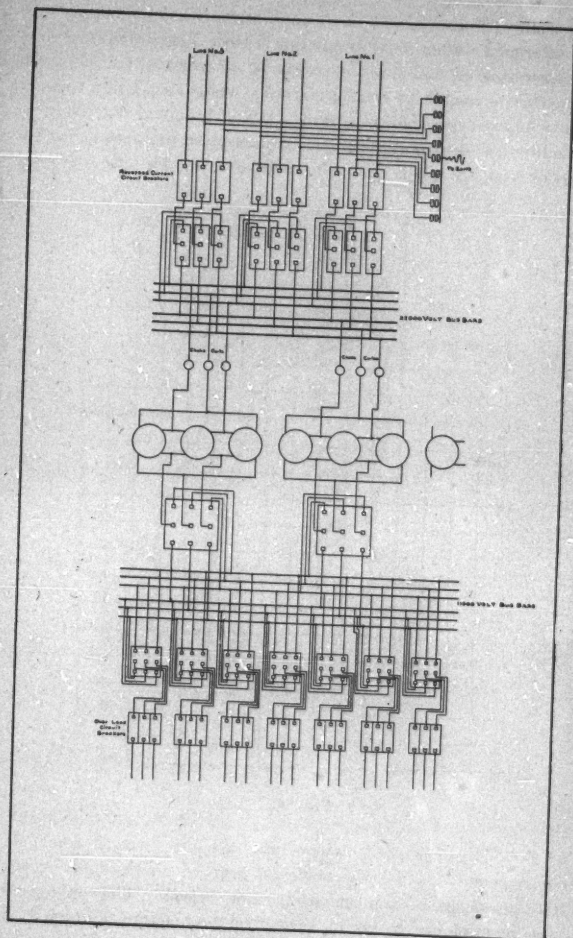


FIG. 11.

alternator. The solid lines show temperature of coil and temperature of external air when water circulation is used. The dotted lines show temperature of coil and temperature of external air when the armature is cooled by ventilation only, water circulation through the armature core being stopped. It will be noted that after the machine has apparently attained its maximum temperature at the end of a run of about $4\frac{1}{2}$ hours, there is a sudden rise of about

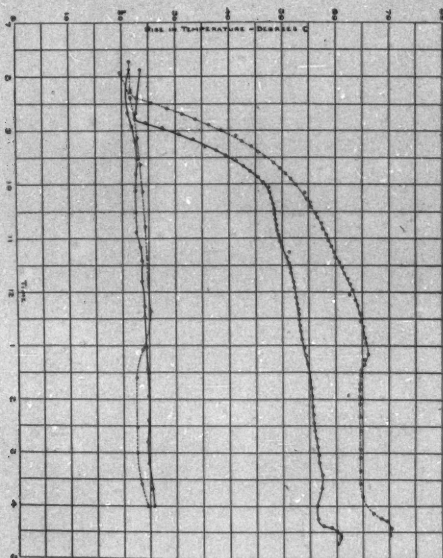
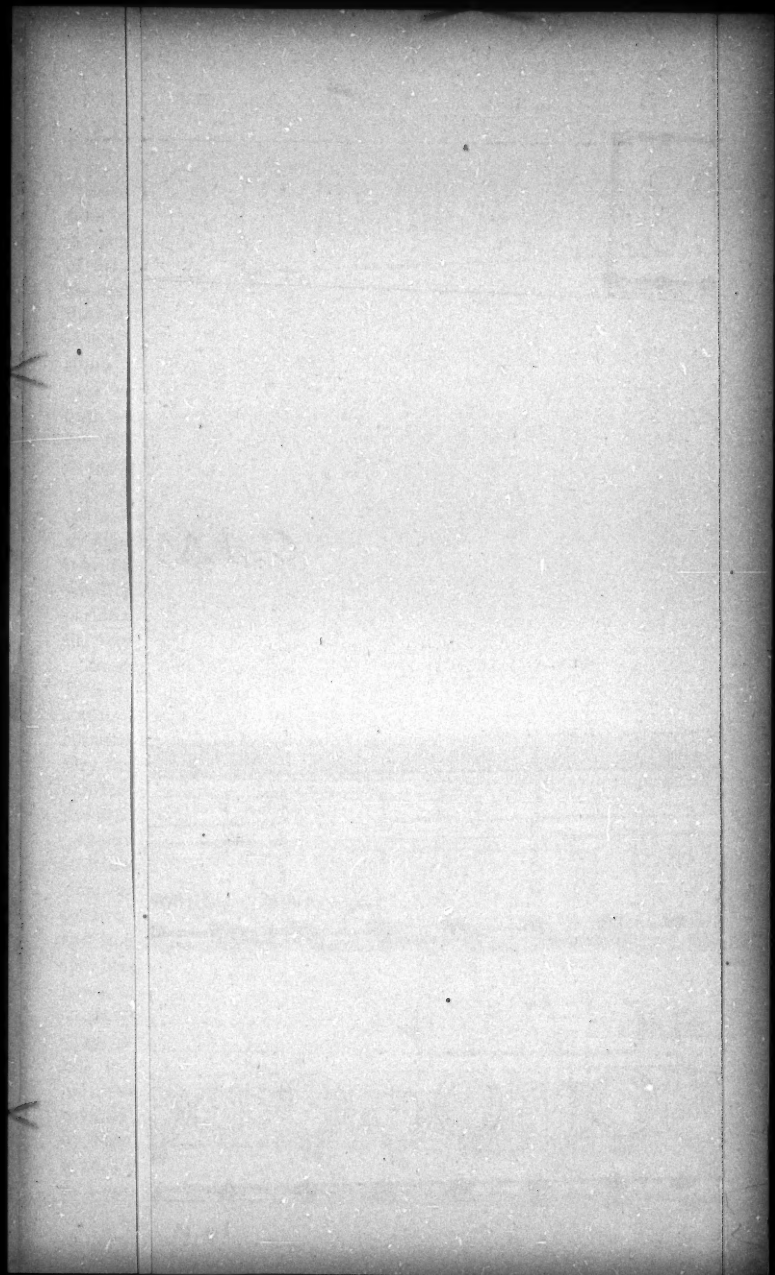
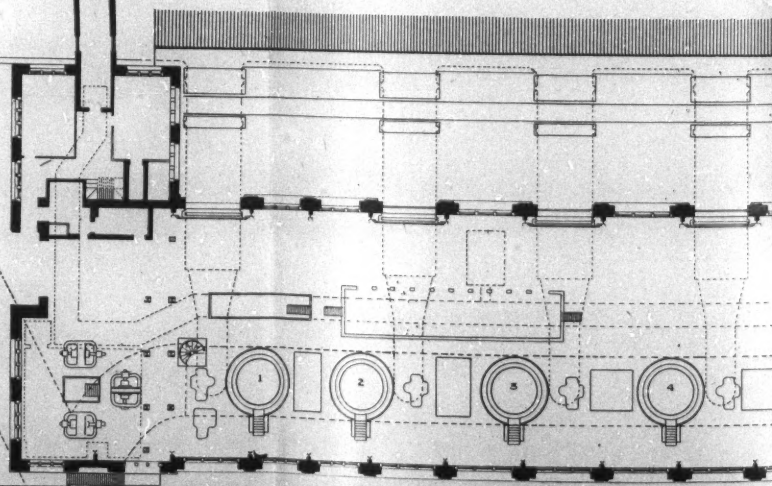
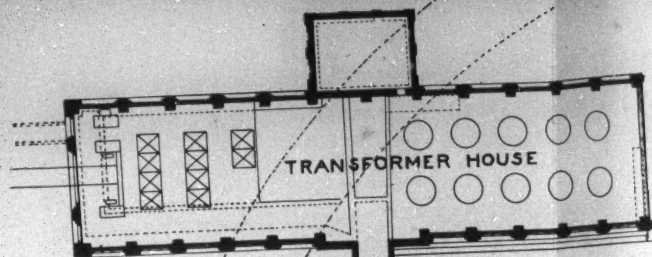


FIG. 12.

5° C. This occurred when the machine was stopped, as a consequence of which the powerful draft of air through the ventilating spaces of the armature core ceased. The sudden rise may be explained by saying that after the machine is stopped, the temperature, which is a maximum in the teeth immediately adjacent to the conductors, tends to equalize itself and a thermal wave spreads inward radially, increasing the temperature of those parts immediately adjacent to the exploring coils.





ANAL

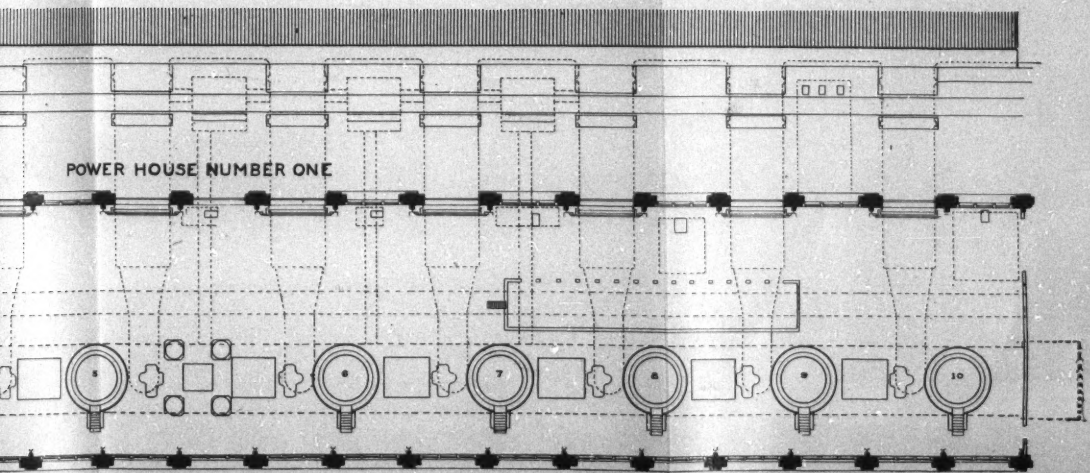
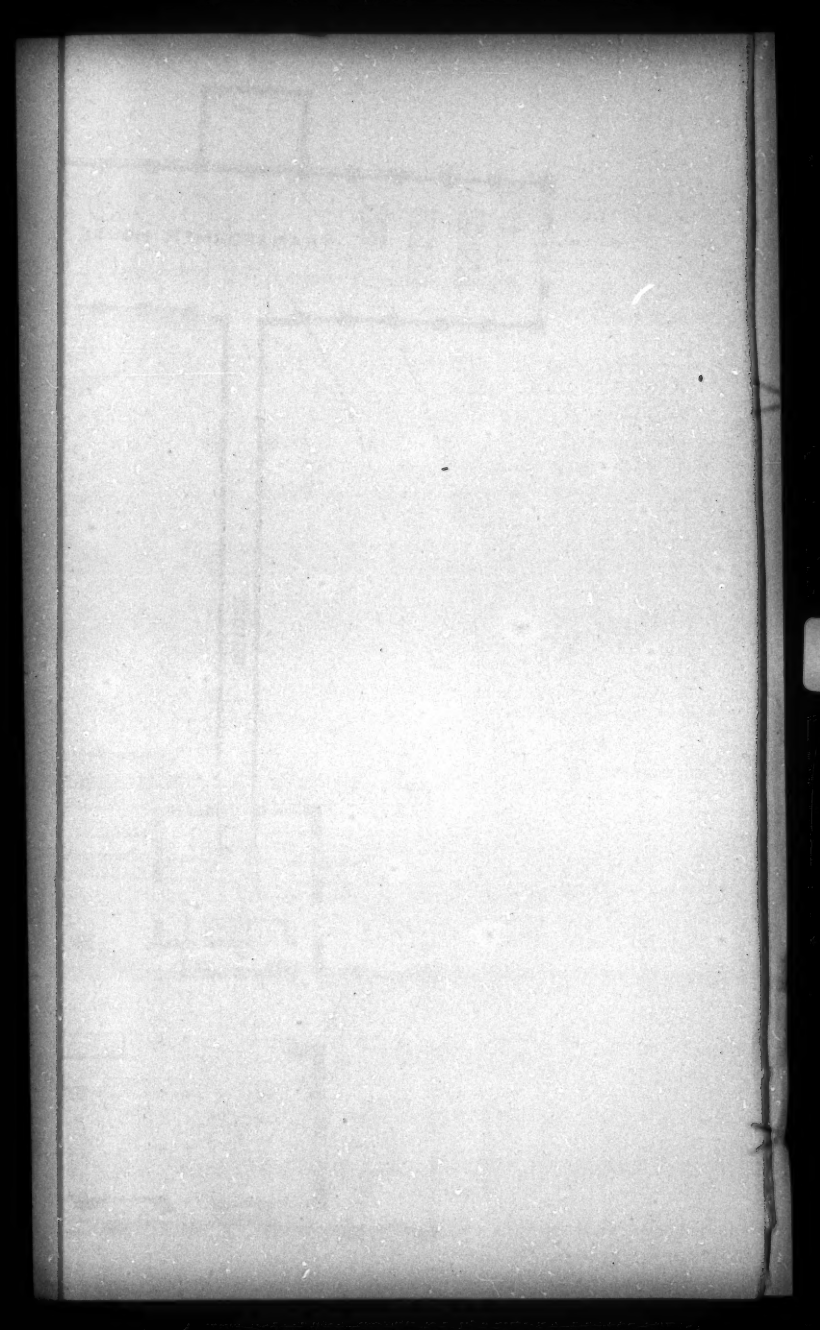


FIG. 13



Insulation Resistance.—Measurement of resistance of insulation by a Wheatstone bridge is of very little practical value as it varies between wide limits, depending upon the temperature of the machine, and the humidity of the air. The only important and conclusive test of insulation resistance of armature and field winding is a test of the dielectric strength by subjecting the insulation to a potential considerably in excess of that which it is designed to withstand in service. It is better of course to use a relatively very high potential for a short time rather than a moderately high potential for a longer time to avoid injuring the insulation. In the factory, the insulation of each bar of the armature winding of the fourth and succeeding alternators was tested by applying 15,000 volts, alternating, for a period of one minute. The insulation of the completed armature as erected in the power-house was tested by applying 6,000 volts, alternating, for a period of 10 minutes between the conductors and the iron core. Insulation of the field winding was tested by applying 2,000 volts, alternating, for a period of 10 minutes. In all of these tests, the form of the potential wave during a half cycle was approximately a sinusoid.

Damage to Armature Winding Caused by Short-Circuits.—

With respect to ability of the armature winding to withstand the strains of magnetic attraction and repulsion caused by short-circuits, the winding of the new alternators proved less satisfactory than that of the first three machines. The magnetic force exerted momentarily by the enormous currents flowing through the armatures and external circuits when a failure of cable insulation resulted in a short-circuit can be realized from the statement that insulated conductors of 1,000,000 c. m. section, weighing upwards of 3 lbs. per linear foot, have been thrown off from their supporting brackets to a distance of 5' or 6', and in at least one instance a cable of this kind was thrown from the brackets on one side of the bridge between the power-house and the transformer-house with such force that a considerable length of it was caught by the projecting cable supports on the opposite side of the bridge and did not fall to the floor. In this instance the cable was thrown a horizontal distance of approximately 5' while falling not more than 2½'. The strain upon the connectors and armature bars of these alternators where they project above and below the core is very great under conditions of short-circuit such as these, and in a number of instances the armature bars of the new alternators

have been sufficiently bent to damage the insulation. This difficulty has been apparently overcome by inserting wooden spacing-strips between the projecting ends of the armature bars. The point is one of importance, and should not be overlooked in the design of large dynamos. The trouble is caused apparently by the excessive stray magnetic field when the machine is short-circuited. The stray field is less in the later machines than in the first three alternators, but the armature bars are but half as thick— $\frac{7}{32}$ " as compared with $\frac{7}{16}$ "—and a greater tangential movement is therefore possible.

Changes Introduced in the Construction of Alternators 4-10 Not Material as Affecting Their Money-Earning Power.—I would ask you to carefully note that the changes introduced in the design and construction of the alternators 4-10 as compared with the first three alternators in no sense materially affect the commercial usefulness of the machines. Considering the machines with reference to their money-earning power, there is little to choose between the first three alternators and their successors. The advantages of the latter may be summed up in the statement that their efficiency is about .3 of 1% higher, that their regulation is somewhat closer, and that their limiting temperature under continuous full load is about 15° C. lower.

The armature insulation of none of the first three alternators has broken down in commercial service, and examination of the insulation of bars which have been in use since 1895 shows no apparent deterioration. It would seem safe to conclude, therefore, that a temperature rise of 60° C. above surrounding air, or absolute temperatures in continuous service ranging from 85° C. to 100° C., acts very slowly, if at all, in causing deterioration of the micanite insulation used in this case. The improvements embodied in alternators 4-10, in so far as they are practically material, are the result of improved methods of manufacture rather than improvements in design.

VIII. THE EXCITERS.

During the period of construction, current for exciting the fields of the alternators was obtained from a 75 k. w. continuous current engine driven generator and from 200 k. w. rotary converters, two of which were installed for this purpose. These converters were of course supplied through step-down transformers and in the winding of these transformers provision was

made for adjustment of the ratio of transformation, and consequently for adjustment of the potential of the continuous current delivered. A rheostat in the field of each alternator affords means for the necessary adjustment of potential.

When the wheel-pit was extended to permit installation of the fourth and succeeding units, provision was made for turbine-driven exciters, of which four are now in use. These exciters, are of 125 k. w. output; their speed is 550 R. P. M. One of them is capable of exciting the entire battery of ten alternators, but it is usual to keep two in operation for this purpose.

Excitation by separately driven exciters is preferable to excitation from rotary converters, since in the latter case variations of potential at alternator terminals are increased by reason of the fact that the potential of the exciting current delivered to the fields varies in sympathy with the changes due to variations in the external load. An increase in load, therefore, reduces the potential delivered to the A. C. circuits not only by reason of drop due to resistance and reaction of armature, but also by reason of a practically simultaneous reduction in strength of field. This of course was understood when the converters were put in, and they were installed only as a temporary expedient, pending installation of turbine driven exciters which could only become possible when the wheel pit was extended.

IX. SWITCHING APPARATUS AND MEASURING INSTRUMENTS.

The design and construction of adequate switching apparatus, properly organized not only with reference to the three alternators originally ordered by the Cataract Construction Company, but also to future extensions of the Niagara development, was not the least difficult of the problems presented by the conditions to be met.

In 1893, no switch adapted to 5,000 horse-power circuits had been constructed and, so far as I am aware, no switch fitted to meet the conditions, both of large current—1,000 amperes per pole—and comparatively high potential—2,200 volts, alternating—had been attempted.

As to the general organization of apparatus, it was necessary to provide not only for the three initial alternators, but also for the operation of additional machines, of which it was expected that as many as 15 or 20 might be located in power-house No. 1, while others, to a possible ultimate number of 40 on the Ameri-

can side of the river and 50 on the Canadian side of the river, might be installed. It was obviously essential also that the switching arrangements must be such as to permit operation of any or all alternators in parallel.

To meet the conditions, it was decided to so organize the switching apparatus as to provide for operation of the alternators in successive groups of five, the alternators of each group being connected to switching apparatus centrally located with reference to the group, with provisions for cross-connecting the bus-bars of different groups so that, if necessary, alternators of different groups might be operated in parallel with each other.



FIG. 14.

In previous organizations of switching apparatus, at least in America, the switches, bus bars and measuring instruments had been assembled upon vertical panels of marble or slate, these panels being supported by a suitable frame work and collectively constituting what is called a "board." This form of construction is an inheritance from the earliest days of the commercial dynamo, when it was natural to place the switch and the ammeter and voltmeter at first upon a wall of the dynamo room, and later—when the advantages of running wires behind the

"board" and the necessity of going behind it to look after connections, etc., had become apparent—upon a vertical switch-board independently supported and separated from the wall of the room by a suitable space.

The dimensions of a switch adapted to a 5,000 H. P. two-phase 2,200-volt alternator, as fixed by size of contacts necessary to carry the current and by distance between terminals required by the comparatively high potential, were such that operation by hand was considered impracticable and it was decided to employ pneumatic pressure to throw the switches. This made it possible

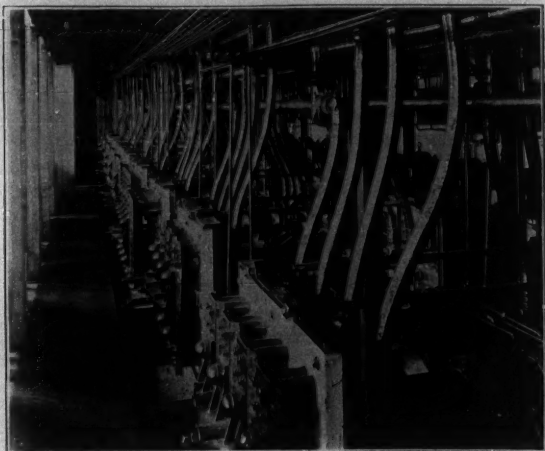


FIG. 15.

to locate the switches at a distance from the operator, who would thus be removed from danger in case of a short-circuit in the switches or a dangerous arc. Danger to the operator from accidental contact with charged terminals would also be eliminated in this way.

These being the general considerations in mind, the switching apparatus for the first group of five alternators was assembled in a switch room, or structure, erected over the cable subway which extends the entire length of the power house on a line parallel

with the row of alternators. The position of this structure, and of a second one subsequently erected for the second group of five alternators, with reference to the alternators, is shown in Fig. 13 and exterior and interior views are shown in Figs. 14 and 15. The 5,000 h. p. switch itself is illustrated in Fig. 16.

The four leads from each alternator are connected to the bottom terminals at opposite ends of a switch; the upper terminals are connected by short pieces of insulated cable to the bus-bars which are supported in a horizontal position above the switches. Two sets of bus-bars are provided and any alternator may be connected to either set. Connections for the feeder switches are

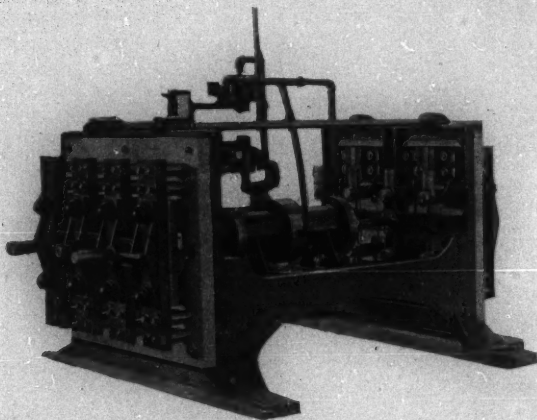


FIG. 16.

similar to those for the alternator switches except that bus-bars are connected to the upper terminals and the outgoing cables to the lower terminals at each end of the switch. The bus-bars are insulated by vulcanized rubber covered with braid and wrapped with twine. After erection, they were subjected to a puncture test of 10,000 volts alternating. The bus-bars taper from the middle toward each end, the section at all points being proportioned to the maximum current which may traverse the bars. They are circular in form, the end sections being copper rods $1\frac{1}{8}$ " in diameter and the intermediate sections copper tubes, the largest being

about $3\frac{1}{2}$ " in diameter. The rods constituting the end sections are threaded and screwed into the ends of the adjacent tubes, which in turn are threaded and screwed into the ends of the large tube constituting the middle section of the bar. The fitting and insulating of these bars was a work requiring much care and skill; it was admirably carried out by Dr. W. M. Habirshaw, Manager of the India Rubber & Gutta Percha Insulating Company, Yonkers, N. Y., which firm also supplied all cables for dynamo leads and connections.

The switches are supported upon I beams which span the cable subway. While I do not regard these switches as absolutely reliable in opening circuits conveying several thousand horse power, they have failed in service not more than two or three times since the plant was started and on the whole have done their work in a very satisfactory manner.

The ammeters and voltmeters, indicating wattmeters and synchroscopes, are mounted not upon a board, but upon individual instrument stands, one stand being provided for each alternator. These stands are located upon the platform which constitutes the roof or ceiling of the switch room. In front of each alternator instrument stand is a smaller one carrying the levers by means of which air is admitted to the switch cylinders. For each feeder circuit, lever stands equipped with pilot lamps and drop indicators are located upon the upper platform of the switch structure within convenient reach of the operator. The drop indicators were not included in the original outfit, but were added at a later date after the feeder fuses were dispensed with. In case of short-circuit, they indicate to the operator which of the several feeder circuits is in trouble. They are constructed very like the drop indicators in a telephone switchboard.

For each phase of each feeder circuit, an indicating wattmeter and a watt-hour meter are provided. These instruments are not placed upon the switch structure, but are located in the Superintendent's office, my theory being, at the time this installation was made, that the switch operator need see only the alternator instruments, while the division of load among the several feeders supplying different tenants of the company was a matter concerning the Superintendent. Incidentally, also, this arrangement by removing from the switching structure a large proportion of the measuring instruments, simplifies the organization of ap-

paratus at that place, and improves the appearance of the platform of the switching structure which would otherwise be awkwardly crowded by instrument stands. An argument in favor of instrument stands as against an instrument "board," which considerably influenced the decision in favor of the former, was the fact that as instrument boards were then constructed it was not easy to put up a board for three alternators arranged for extensions to take care of additional alternators which would not look unfinished and incomplete until such time as the additional alternators might be installed.

The alternating current measuring instruments used are of a very interesting type, invented by the late O. B. Shallenberger, whose untimely death in 1898 was a most serious loss to applied science in electrical engineering. In their various modifications, these instruments constitute a complete series of indicating and integrating meters for single or polyphase alternating currents.

The 5000 H. P. Switch.—Fig. 16 shows the general arrangement and construction of one of the 5,000 H. P. two-way four-pole switches. Two independently operated pistons working in air cylinders placed back to back are used to open and close the switches. The current carrying contacts are of the ordinary blade and jaw type. In opening the switch when the moving blades leave the contact jaws, the arc, which would otherwise occur, is prevented by a shunt circuit having a considerable resistance. The small current which flows through this resistance is finally broken at auxiliary terminals of the plunger and socket type, the material used for these terminals being a certain quality of brass which does not readily arc. The non-arcing qualities of this material were discovered by Alexander J. Wurts and utilized by him in his well-known and valuable lightning arrester for alternating current circuits. Its utilization in these switches in combination with a shunt resistance is due to Mr. H. N. Potter. On the whole, these switches have been very satisfactory in operation. They cannot be relied upon to open the circuit under short-circuit conditions, and were never intended for that purpose. They have been used, however, to open the circuits when delivering large amounts of power, and they have done this successfully. Under test conditions they have repeatedly opened, without injurious sparking, currents exceeding 600 amperes per phase. In opening the circuit by this switch, under the conditions existing in service, no appre-

cial rise of potential occurs. This point has been thoroughly demonstrated, as it was deemed possible that in suddenly opening heavy power circuits of considerable inductance and capacity, momentary abnormal rise of potential might be experienced. That no excessive rise does occur has been conclusively proved by tests, the method used being to place in parallel with the switch a spark-gap, consisting of two sharp terminals separated by an adjustable and known space.

Automatic Circuit-Opening Devices.—In the original outfit of switching apparatus no fuses or circuit-breakers were used in the leads between the alternators and bus-bars, nor has experience ever indicated that they are desirable in these circuits. The leads from alternators to bus-bars are not long, and the potential is but 2,200 volts, alternating.

The conductors used have an $\frac{3}{8}$ " wall of vulcanized rubber, containing 30% pure Para, this insulating wall being covered by a heavy braid, treated with compound to exclude moisture. Those more recently put down, over this braid have also a braid treated with a fire-proof composition. With such insulation there is less danger of a break-down between alternator terminals and bus-bars than there is in the armatures themselves, and considering the uncertainty of action of any automatic circuit-breakers or fuses available at the time, it was decided, I believe wisely, to install nothing of the kind in the alternator leads.

As regards feeders, the arguments in favor of automatic circuit opening devices are much more weighty than in the case of the alternator leads, since occasional failures of cable in an extensive system of distribution are inevitable, and without automatic opening devices in the feeder circuits the entire battery of alternators connected to the affected circuit must be shut down in case of trouble. A serious effort was therefore made to provide suitable automatic circuit opening devices. No circuit breakers having been developed for this kind of service, fuses of a type furnished by the Westinghouse Company and unquestionably the best available at that time were adopted. These fuses had some ingenious and excellent features, but in service ultimately proved a failure, and in 1898, after a year's experience in charge of operation of the plant, I removed all of them, and since then the plant has been operating without any automatic circuit-opening devices in the local distributing feeders at the power-house. Where the feeders enter the premises of the tenants using the power, fuses were ori-

ginally used, and these have since been succeeded by circuit-breakers of which, several types are now in service. The fuse originally used in the feeders at the power-house is of aluminium, and is enclosed between two *lignum-vitæ* blocks, in which spaces for the three parallel fuse strips are cut out. The arrangement is a development of the expulsive type of fuse, vents from each of the three fuse chambers being provided, through which the vapor of the exploding fuse is expelled. The *lignum-vitæ* blocks are hinged at one end, and when closed are held together securely at the other end. When the blocks are in perfect condition, so that the only outlet for the gas formed by the explosion is through the vents provided for the purpose, they are effective, as was demonstrated not only by tests at Niagara preceding their adoption, but also by their action in commercial service. But in practice, owing to gradual shrinkage of the blocks the exploding gas sometimes reaches the terminals and the fuse fails to clear. It was found in practice that the fuse itself, which having exposed terminals is necessarily an imperfectly insulated link in the circuit, caused more trouble than it prevented, and its use was therefore abandoned. Until the work of placing the local distributing cables in properly constructed conduits was completed, about two years ago, short-circuits upon some of the local distributing cables occurred much more frequently than was desirable, and the local service was occasionally interrupted when it probably would not have been interrupted if automatic circuit-breakers, such as can now be obtained, had been in use upon the feeder circuits. Since the work of relaying the cables has been completed, however, interruptions of local service due to failures in cables have been extremely rare, and as there is no space conveniently available in Power-house No. 1 for the installation of feeder circuit-breakers it has not been thought wise to introduce them. Plans for Power-house No. 2, however, contemplate the use of automatic circuit-breakers, and since adequate space will be provided for the improved types now available there is every reason to believe that they will be successful. Marked progress in construction of circuit-breakers for high potential and large power circuits has been made since 1893. To this progress the experience and requirements of the Niagara Falls plant have in no small degree contributed, and some most interesting and instructive tests of automatic circuit-opening devices have been carried out jointly by engineers of the manufacturing companies and the staff of

the Niagara Falls Power Company. I regret that the limits of this paper do not permit discussion of some of these tests.

Fuses and Circuit-Breakers on Long-Distance Transmission Circuits.—With regard to the circuits used for transmitting power to Buffalo and other distant places, the original outfit of switching apparatus in the power-house included fuses of the expulsion type above described. These fuses were located in the switch-room, and were mounted and connected exactly as are those used in the local distributing service—all feeder circuits, in fact, being treated alike in this respect.

When I became Electrical Director of the Cataract Construction Company and the Niagara Falls Power Company in March, 1897, the Buffalo service, which then amounted to less than 2,000 H. P., was supplied at 11,000 volts over transmission circuits which have been described by Mr. J. G. White in a paper read before the National Electric Light Association in June, 1897. At Niagara three 930-k. w. step-up transformers, supplied by the General Electric Company, and of the well-known air-cooled type, were installed, two being in service and one held in reserve. The connections used were and still are the two-phase, three-phase arrangement. Lead fuses, mounted upon a marble panel, had been placed in the 2,200-volt circuit on one side of the step-up transformers and aluminium fuses, also mounted upon a marble panel and separated from each other by wooden barriers, were used in the 11,000-volt three-phase circuit.

In Buffalo, in a small room adjacent to the power-house of the Buffalo Railway Company, three 250-k. w. transformers, connected in delta, received from the transmitting circuit three-phase current at about 10,000 volts and delivered three-phase current at 375 volts to two rotary converters, which in turn delivered direct current to the circuits of the railway company. In the 11,000-volt circuits supplying the step-down transformers, aluminium fuses similar to those used on the high potential side of the step-up transformers at Niagara were inserted. There were no fuses between the step-down transformers and the converters, but circuit-breakers were used in the direct current circuits leading from the converters to the main bus-bars of the Railway power-house, to which power was supplied not only from these converters, but also from a number of direct-current steam-driven dynamos. The fuses thus arranged were found to be far from satisfactory, a short-circuit on the transmission circuits in Buffalo usually blowing every

fuse between the point where the short-circuit occurred and the bus-bars at Niagara. Attempts to prevent this by so adjusting the size of the several sets of fuses in series with each other as to permit only fuses at Buffalo to blow in case of trouble beyond them, and the high potential fuses at Niagara to blow only in case of trouble on the transmission line between them and the Buffalo fuses, did not succeed. Moreover, the 11,000-volt fuses sometimes failed to clear without practically destroying their terminals and the 2,200-volt lead fuses, which contained a considerable quantity of metal, usually destroyed terminals and barriers, and continued to arc until the power was cut off.

As the long distance service increased in amount and power was supplied to other substations in Buffalo and other places, the necessity of automatic circuit opening devices, which would localize trouble by opening branch circuits without opening the main transmission circuits at the Niagara end and so interrupting the entire long distance service, became very urgent and to meet these conditions the time-limit relay circuit breaker was devised. The first of these circuit breakers was designed in detail and constructed by the General Electric Company.

These circuit-breakers are essentially the well known General Electric railway circuit breaker without the secondary break and blow-out coil, the trip coil being wound not with the main circuit, but with an auxiliary 100-volt winding supplied from a transformer, the circuit being closed through this coil by a clock-driven contact. The magnet in the main circuit controls a stop device which releases the clockwork which may be set to make the contact and trip the breaker at the expiration of a pre-determined time interval. The current carrying contacts of the breaker are shunted through long, fine fuses placed in cylinders of wood, which are provided with vents, or chimneys, through which the gas of the exploding fuse may escape. When the shunt fuse is properly connected to the circuits, these breakers open the circuit so far as has been determined without momentary rise of potential and usually without burning the current carrying contacts. It is necessary, however, to use great care in replacing a shunt fuse, as any failure to make a perfect connection of the shunt will result in the destruction of the breaker the next time it is called upon to act.

A number of these, and also a number of time-limit circuit-breakers as constructed by the Westinghouse Electric and Mfg.

Co., are now in use in Niagara and in Buffalo. The essential feature of the time-limit circuit-breaker is the use of an adjustable time measuring device which is started when the current passing through the circuit-breaker exceeds a certain predetermined value and which is used to open a circuit-breaker at the expiration of a predetermined time interval. No matter how great the current passing through the circuit-breaker may be, it cannot open automatically until a definite and predetermined time has elapsed.

The diagram Fig. 9 illustrates the connections of the power circuits between bus-bars at Niagara and the feeder circuits radiating from sub-stations in Buffalo. The diagrammatic connections shown appear simple enough but the actual connections are necessarily very complicated. This will be realized upon inspection of Figures 10 and 11, illustrating respectively the actual connections in the step-up transformer house and in the Buffalo terminal house, where the step-down transformers are located. In Fig. 9 I have shown but two alternators with their switches, one feeder switch, one pair of step-up transformers, one group of three step-down transformers and a single group of step-down transformers in each of the five sub-stations. As a matter of fact, four and sometimes five alternators are used to supply the long-distance service. Eighteen step-up transformers are installed at Niagara. Three transmission circuits are available, and two are normally used. Seven step-down transformers are provided in the Buffalo terminal house and from this terminal house eight sub-stations, each containing from three to upwards of twenty step-down transformers, are supplied. A very large number of distributing circuits radiate from sub-stations in Buffalo. It will be seen at a glance, therefore, that so extensive a system involves necessarily a large degree of complication. Occasional accidents to the system in one part or another are practically inevitable, and since the system, overhead and underground, is interconnected, the problem of localizing trouble resulting from a failure of insulation or from other accident is a very difficult one. The attempt has been made to solve the difficulty by the use of the time-limit circuit-breaker, but up to date the results have not been entirely satisfactory. Failures, however, have been due to the circuit-breaking parts and not the time limit device which, in connection with circuit-breakers that can be relied upon to open their respective circuits, is unquestionably a valuable feature. Referring to Fig. 9, time-limit cir-

circuit-breakers should be set as follows: (1) In 22,000-volt circuits at step-up transformer house, the relays should be set to actuate circuit-breakers at expiration of about three seconds; (2) in 10,000-volt cables connecting transformers in Buffalo terminal house to sub-stations, they should be set to open in somewhat less time, *e. g.*, one second; (3) in distributing circuits from step-down transformers in the various sub-stations, they should be set to open instantly. If a short circuit then occurs upon one of the branch lines from a sub-station, the circuit-breaker in that branch should open instantly, cutting off the supply of power to the branch without interruption of service throughout the general system, but unfortunately no circuit-breaker can open instantly. This being so, when the short circuit on the branch occurs, the clock mechanism of the circuit-breakers in the 10,000-volt circuit at the terminal house starts as does also similar mechanism in the circuit-breakers of the high tension lines at Niagara. As soon as the circuit-breakers on the branch at the sub-station have cleared, which will happen in a very small fraction of a second, the relay tripping device in the 11,000 and 22,000-volt circuit-breakers becomes inoperative, and these circuit-breakers reset themselves automatically. If for any reason the circuit-breaker in the local distributing circuit which is in trouble should fail to clear that circuit, the clock mechanisms of the circuit-breakers in the 11,000 and 22,000-volt circuits will continue to revolve until one second has elapsed, when the circuit-breaker in the 11,000-volt circuit will open and clear the circuit. The breakers in the 22,000-volt circuit at Niagara being set for three seconds cannot yet open and they automatically reset themselves.

This, however, is theory rather than practice, as owing to failure of circuit-breakers to clear their circuits the operation of the time relay cannot be said to have accomplished its object as yet. But I believe, that circuit-breakers capable of opening these circuits, even under the extreme conditions prevailing when a branch is short circuited, will be developed, and that the time limit device in conjunction with such breakers will solve the problem. At the present time, owing to the failure of the 11,000-volt circuit-breakers at the terminal house and the 22,000-volt circuit-breakers at the step-up transformer house to clear their circuits, the time limit device is not used at these points.

That time and experience should be required for the development of circuit-breaking apparatus adapted to circuits con-

veying thousands of horse-power at 10,000 and 20,000 volts is not remarkable. Indeed, it has been strongly urged that no attempt should be made to open the power circuits while conveying large working currents. In a paper on "The Electric Transmission of Power from Niagara Falls," read before the British Institution of Electrical Engineers November 9, 1893, the author, who at that time was Consulting Electrical Engineer to the Cataract Construction Company, speaking of abnormal momentary rise in electric potential says: "As to the cause of trouble mentioned above, I hold that it is a piece of culpable ignorance, ruinous to the machinery, if any one should ever on a large power circuit with alternating current suddenly break the circuit while current is passing. This practice is quite unnecessary, and has given rise to a large proportion of breakdowns of alternating current machinery." In my opinion, this view is one well worthy of consideration. The answer of course is that unless provision is made for breaking the circuit while current is passing it becomes necessary to shut down the entire plant supplying Buffalo, Tonawanda and Lockport every time insulation fails in any part of a vast system of overhead conductors, underground cables and transforming machinery installed throughout the extensive territory supplied from the Niagara plant. But if in opening a branch circuit in order to localize trouble and avoid an interruption of the entire service the insulation of important parts of the system be subjected momentarily to extremely high potentials it may be argued reasonably that it would be better practice to provide no circuit opening devices, aim to make the insulation of the entire system so perfect as to avoid any breakdowns, and when accidents did occur cut off the entire supply of power until the cause of trouble is removed. It has been my view that automatic circuit-breakers to localize trouble were essential,—that the problem must be faced and solved.

In 1894, the 5000 horse-power pneumatically operated switch was tested in opening circuits of high inductance, an adjustable spark gap being placed in parallel with the break and the fact was established that for the circuits used, which were thought to fairly represent the most severe conditions to be expected in practical service, this switch could be used without danger of abnormal momentary potential. As this switch does not suddenly open the circuit through which the current of perhaps 1000

amperes is flowing, but opens it through a resistance arranged as a shunt around the main contacts of the switch, the result demonstrated by the tests is accounted for, and in fact the switch was designed on these lines, not only with a view to opening the circuit without damage to the switch itself but to do so without causing momentary rise of potential. Similarly, tests of fuses, enclosed in *lignum vitæ* boxes, provided with a vent for the escape of gas showed no abnormal increase of potential in breaking the circuit. At a later date, tests of carbon shunt circuit-breakers, which in opening the circuit draw a long arc of carbon vapor, were tested and no excessive rise of potential was noted; and at a still later date Mr. Steinmetz, at Schenectady, tested circuit-breakers of the type which open the circuit under oil, and he found no dangerous rise of potential. In the case of the tests at Pittsburg in 1894, and also in the case of tests by Mr. Steinmetz, the circuits opened were supposed to be thoroughly representative of extreme conditions to be met in practical service. It is apparently established, therefore, that the danger of causing oscillations of extremely high potential in automatically opening alternating current power circuits operating at 25,000 volts has been surmounted. Nevertheless, up to the present time experience with circuit-breakers at Niagara has not been satisfactory. The conditions are extreme and the causes of the failures which have occurred have been recognized and in some degree removed, but further improvement is to be desired, and I suggest that in the discussion of this paper those who have given special attention to the design, construction and use of circuit-breaking switches let the INSTITUTE have the benefit of their study and experience.

In aiming to secure satisfactory automatic control and separation of circuits in case of accidents, as I have said, the time element relay circuit-breaker was introduced for the purpose of localizing trouble by cutting off the branch circuit affected without interfering with continuity of service through other branches or supplied through the same trunk lines. In addition to this, the reversed current circuit-breaker was installed at the Buffalo end of the line for the purpose of automatically disconnecting from other circuits in that city any one of the overhead transmission circuits from Niagara which might become short-circuited. Reversed current circuit-breakers, I believe, were first used at Hastings, England, where they were connected in the

circuit between alternators and bus-bars. Those which have been used in connection with the Niagara plant consist essentially of a circuit-breaker similar to those used for opening circuits under abnormal overloads excepting that the usual tripping coil is omitted and a tripping device actuated by reversal of current substituted. In one type, the tripping device is simply a motor, one element of which is energized from and is consequently approximately in phase with the bus-bars, to which two or more incoming circuits are connected, while the other element is connected into and is therefore in phase with the current traversing the circuit which under certain conditions it is intended to open. In another type, and one which is probably more certain in action because less affected by the radical displacement of phases which accompanies short-circuits, the elements of a Shallenberger meter are used, the disk normally tending to rotate in a given direction but being held by a stop when the current through the series element is normal. In case of a short-circuit on the line, the direction of current through the series coil is momentarily reversed, while that through the shunt coil, which is connected to the bus-bars, though shifted in greater or less degree remains in phase with the incoming circuit which has not been short-circuited; consequently the disk tends to rotate in an opposite direction, and, being free to move, revolves through a certain angle and closes an auxiliary circuit which opens the breaker. In three-phase circuits, the connections are complicated, and owing to the radical displacement of phases which occurs when lines are short-circuited, I regard none of these devices as thoroughly reliable, although they have some times acted satisfactorily.

X. TRANSMISSION AND DISTRIBUTION.

In the report of Prof. W. C. Unwin, Secretary of the International Commission, which in January and February, 1891, considered no less than 22 plans for the development of Niagara power, which had been submitted in compliance with an invitation from the Cataract Construction Company, it is stated that "There were two or three points of primary importance as to which the Commission came to a definite expression of opinion." One of these related to the distribution of power by electrical conductors and the language of the Secretary's report is as follows:

"On a third point the Commission came to a conclusion which departed from the view taken by any of the competitors. They considered that it would be necessary to have a tunnel, or subway, in which to place the main electrical distributing conductors; in such a subway the conductors could be of bare copper, placed on insulators. If the conductors were so placed in a subway, the greatest facility would be afforded for erection, for repairs, for inspection and for cleansing and there would be the greatest security from accident due to lightning or rain or snow, or to provide against public wanton mischief. These considerations appeared to the Commissioners to be so important that they would justify the excessive cost involved in the construction of the subways, which, however, would probably not be great."

Beyond doubt, such a subway, if large enough to admit of proper spacing of bare conductors carrying 20,000-volt currents and supported upon porcelain or glass insulators, would possess the advantages pointed out by the Commission, but unfortunately its cost is so great as to be quite prohibitive, unless the power transmitted through it is very large in amount, *e. g.*, 50,000 k. w. However, at the outstart the company actually did construct a tunnel, or subway, about half a mile in length, extending from the power house to a point near the works of the Pittsburg Reduction Company.

This tunnel was designed by Prof. Forbes and has been fully described by him in his paper of November, 1893. He proposed to use bare copper conductors supported upon porcelain insulators and carrying 20,000 volts for both local and long distance work, but the alternators finally adopted being wound for 2,200 volts the subway has never been used as originally expected.

Quite apart from considerations of cost, its dimensions are too restricted, in my opinion, to permit satisfactory working with bare conductors at any such potential as 20,000 volts, but setting aside the question of practicability, its actual cost exceeds by not less than \$50,000 a mile the cost of a pole line such as that erected by the company last year. At the present time, exclusive of the power used temporarily for lighting the Pan-American Exposition, about 12,000 k. w. are delivered in Buffalo at time of maximum load. The cost of a tunnel from the power house to the new terminal house in Buffalo, a distance of 23 miles, would exceed the cost of the new pole line by not less than \$1,200,000 and the increased investment required, upon the basis of present business in Buffalo, would approximate \$100 per kilowatt delivered at time of maximum load. On the basis of

3,000 k. w. delivered, the difference in cost of tunnel and pole line would of course be \$400 per k. w. delivered, and since at the outstart the company was able to contract only for some 3,000 k. w. in Buffalo, the reason why the directors decided to use overhead construction instead of a subway is sufficiently obvious. It is to be noted that the commercial feasibility of a subway for electrical conductors depends primarily upon the amount of power transmitted. Had it been possible at the outstart to contract for the sale of 30,000 kilowatts in Buffalo, a subway might have been practicable, but even then to allow not only for proper spacing of the cables, but for convenient and safe inspection and maintenance, it should have been made considerably larger in section than was the case with the comparatively short length actually constructed and this of course would have made it still more expensive. For local distribution, with its branch lines and ramifications, such a subway construction is entirely unsuitable. In 1893 cables that could be relied upon for working with 10,000 volts potential could not be procured and the company's decision to adopt an overhead construction for transmitting power to Buffalo was the only one justified by the state of the art. Since that time, manufacturers of cable have realized great improvement in quality and effected radical reduction in cost and coincidentally with these changes the sale of power in Buffalo has steadily increased. It is expected, therefore, that the day will come when underground cables will be employed for this transmission.

The Local Distributing System.—With the details of the early evolution of the local system of distribution used by the company I am not familiar. In March, 1897, power was supplied to local tenants, whose works for the most part were located upon the land of the Power Company, in amounts approximately as follows:

The Pittsburg Reduction Co.	3,195	E. H. P.
The Carborundum Co.	1,000	"
Acetylene Light, Heat and Power Co.	1,000	"
Niagara Electro-Chemical Co.	400	"
Buffalo & Niagara Falls Electric Light and Power Co.	500	"
Buffalo & Niagara Falls Electric Railway.	300	"
Niagara Falls & Suspension Bridge Railway Co.	250	"
The Niagara Falls Water Works Co.	45	"
Hygeia Ice and Refrigerating Co.	40	"
The Cataract Power and Conduit Co.	1,000	"

The power used by the railways was delivered in the form of direct current at about 570 volts, three 500 H. P. rotary conver-

ters with step-down transformers having been installed inside the power house for this purpose. With this exception, the entire output of the plant was conveyed through single-conductor cables of 1,000,000 c. u. section from the bus-bars of "switch-board No. 1" through the subway and bridge connecting the power house with the transformer house. A cross section of the bridge is shown in Fig. 24.

In the transformer house, those cables used for the long distance service were connected to the step-up transformers while beyond the transformer house power was conveyed to local tenants through single conductor lead covered cables, the majority of which were of the section above mentioned.

From the transformer house to a man-hole near the works of the Pittsburgh Reduction Company the cables were carried through the subway tunnel, to which I have referred.

Iron brackets had been erected on each side of the tunnel at intervals of five feet and upon these a majority of the lead-covered cables were supported, although some of them had been simply drawn into the tunnel and rested upon the floor. A cross section of the tunnel is shown in Fig. 25.

There was no provision in the way of conduits for the cables which extended from the man-hole at the end of the tunnel to the works of the Mathieson Alkali Company, the Niagara Electro-Chemical Company and the Niagara Electric Construction Company. The cables leading to these works had simply been laid upon the top of the ground and extended across the fields to the several establishments supplied with power.

Naturally these cables, although not extending outside the limits of the company's property, were subjected from time to time to mechanical damage by reason of carelessness and malicious mischief, and the local service was considerably interfered with. The work of reconstructing and extending the local distributing system was therefore taken up and pushed to a conclusion, the system now used, except the subway, being second to none. As evidence of this, it may be mentioned that for the last two years interruptions of the local service, even momentary in duration, have been extremely rare. A brief description of the steps taken to effect this result may be interesting.

Pending the completion of proper conduits, the cables beyond the end of the tunnel were placed temporarily in wood boxes for mechanical protection, and following this tile conduits were constructed.

For the double purpose of effecting removal from these boxes of the cables in use without interruption of service to the tenants and providing an alternative set of cables to the works of each tenant to be promptly substituted for the usual working cables in case of break-down, the company put down four 1,000,000 c. m. spare cables, making connections from these to the works of each of the tenant companies, who could be reached thus without prohibitive expense. In the works of each tenant company to which this relay cable was extended, four two-way, double-blade, single-pole switches, suitably mounted, were installed, the spare cable being connected to one set of terminals, while the cable ordinarily used by the tenant was connected to the other set of terminals. The leads from these switches to the electrical apparatus of the tenant company were connected to the middle points of the two-way switches.

The double-blade switches were so constructed as to permit either of the two blades to be independently transferred from one contact to the other, thus making it possible to supply the tenant from the cable ordinarily used, from the spare cable or from both at the same time. This arrangement is now in use, and is very effective. For transfer from one cable to the other in time of emergency, and for testing purposes the switches are most useful.

From the end of the cable tunnel, a 36-duct conduit was put down extending to a man-hole on Adams Avenue, immediately north of the works of the Mathieson Alkali Company. The section of this conduit is square, the three inch tile ducts being laid in six horizontal rows, each comprising six ducts. It is laid upon four inches of concrete and protected on the sides by two inches and on the top by about three inches of concrete.

During the summer of 1899 it became necessary to provide conduits and cables to connect the power-house with the new works of the Union Carbide Company, which are located on the land of the Power Company, at a distance of about $2\frac{1}{4}$ miles from the power-house, and it was decided to put down a trunk conduit having a number of ducts sufficient to provide not only for the Carbide Company, including its contemplated extensions, but also for other tenants who in future may locate in the same vicinity. For the Carbide Company, immediate provision was to be made to the extent of 15,000 h. p., with necessary spare cable.

The use of power by the Carbide Company, and by the majority of the tenants of the Power Company, does not vary

from hour to hour between wide limits, as is usual in lighting or railway service, but remains almost constant. This fact, in connection with the very large amount of power for which provision had to be made, led to careful consideration of the subject of heat in the conduits and its probable effect upon the cables. Prior to this, my attention had never been particularly directed to the question of heat in conduits, but upon consideration it was at once obvious that the usual construction of a conduit comprising a considerable number of ducts is admirably adapted to prevent the dissipation of heat caused by the currents traversing the cables.

Failing to secure from the manufacturers of cables and ducts any definite information with regard to the relative temperature of different ducts in a conduit as affected by their location with reference to other ducts and the surrounding earth, an experimental test was made for the purpose of securing light upon the subject. The result of this test demonstrates the great importance of taking into account the dissipation of heat in cases where cables conveying large amounts of power are used. I quote from a memorandum prepared immediately following completion of the test:

"Losses in Cables.—The problem of dissipating the heat of the cables demands careful consideration, as no conduit conveying 25,000 H.P. at 2200 volts has ever been put down, and the losses are necessarily considerable. These losses are of two kinds: (1) Losses due to resistance of the copper conductors; (2) Losses due to currents induced in the lead sheaths.

If twelve 1,000,000 c.m. cables be used to convey 15,000 H. P. by two-phase transmission at 2200 volts, the current through each circuit consisting of an outgoing and return cable delivering 2500 E. H. P. (1865 K.W.) is 848 amperes. The resistance of the cable per linear foot is .00001035 ohms at 68° F. The loss of energy per linear foot of conductor is approximately 7 watts, and when a considerable number of such cables carrying this amount of energy continuously for twenty-four hours per day, are placed in tile ducts constituting a conduit as ordinarily constructed, it is evident that the problem of dissipation of the heat must be carefully investigated.

"With regard to the thermal drop between the copper conductor and the outer surface of the lead sheath, the difference of temperature of the lead sheath and surrounding air, in order that the former may give up the whole or part of its heat to the latter, the thermal drop through the wall of the duct, the effect of the proximity of other ducts, the thermal drop from the conduit (which is surrounded by cement) to the surrounding earth,

the heat conduction of the surrounding earth—particularly when very dry—and the tendency of the ducts to ventilate themselves where opportunity is offered, through manholes, we have been able to secure no satisfactory data from manufacturers of cable or others. We have, therefore, carried out a somewhat elaborate test, using 24 ducts of our 36-duct conduit, between two manholes about 140 feet apart, and situated in the vicinity of the Pittsburgh Reduction Co.'s works. Through each of these ducts, a No. 6 "drawing in" wire has been drawn, and these wires have been connected together at alternate ends in such a way as to put eight wires electrically in series, the 24 wires thus constituting three groups of eight wires each. Through these wires direct current from the works of the Pittsburgh Reduction Co. has been conveyed in quantity sufficient to cause a loss of energy of from 5.5 to 6 watts per linear foot. The test has been continued for about ten days and nights, and during this time hourly readings have been taken of the current in each section, the voltage across each section and the voltage across each two adjacent wires of each section. The ducts comprising each of the three sections have been so chosen that all ducts of one section were adjacent to the earth on at least one side, four ducts of another section were adjacent to the earth on one side, while the other four were separated from the earth by at least one other duct, and the eight ducts of the third section were all separated from the earth by at least one other duct.

"Readings of temperature by thermometer were taken in the manholes and in the ends of the various ducts. The more important and accurate determination of the rise of temperature, however, was made at intervals by stopping the flow of current through the conductor and taking bridge measurements of the resistance of each pair of conductors after allowing an interval of from ten to fifteen minutes to elapse in order that the wire might assume the temperature of the air surrounding it in the ducts.

"The results obtained are of great importance. It is shown that when the loss per duct foot equals 5.5 watts, the rise of temperature of the air in the duct above the temperature of the earth surrounding the conduit may be as much as 80° C. This applies to ducts which are separated on all sides from the surrounding earth by at least one other duct. The rise of temperature in the case of ducts which are next to the earth on one side, is about 60° C., equals 108° F.

If we assume that the temperature of the earth surrounding the conduit may in the summer rise to 70° F., it follows that the temperature of the air in the inner ducts may go as high as 214° F., while the temperature of the air in the outside ducts would be 178° F. under the same conditions.

Coincidentally with our test, Mr. Henry W. Fisher, Electrician of the Standard Underground Cable Co., of Pittsburg, at our suggestion, has been making tests to determine the ther-

mal drop between the copper and the lead sheath of a cable, insulated with $\frac{6}{32}$ " paper insulation, and the thermal drop between the outer surface of the lead sheath and the surrounding air. From Mr. Fishers's tests, it seems safe to assume that the rise of the temperature of the copper conductor above the surrounding air in the duct, will not exceed 40° F.

Now, if to convey 15,000 H. P., twenty-four 500,000 c. m. cables are used, we find by calculation that when the temperature of the ground surrounding the conduit is 70° F., the temperature of the copper conductor will approximate 215° F.

This temperature is excessive. It may be reduced (a) by ventilation; (b) by increasing the size of the conductors. If we make the size of each conductor 600,000 c. m. we have the following results:

Loss per duct foot.....	8.675 watts.
Rise of air in duct.....	94° F.
Rise of copper conductor above air in duct.....	31° F.
Maximum temperature of copper conductor.....	195° F.
Total loss in cables — 24 x 11,500 x 8.675 watts —	1,014 k. w.

Considering these results simply with regard to the life of the cables as affected by the temperature attained, it is evident that the temperature is too high for rubber insulated cables and probably quite as high as can be permitted wisely if paper insulated cables be used. As an alternative to the use of single conductor cables, the use of three-conductor cables working at 10,000 volts and supplied through step-up transformers was considered and finally adopted."

Referring to this plan, I again quote from my memorandum:

"Plan B. 10,000 - Volt Transmission, Three-Conductor Cables and Sub-Station.—In considering this plan, the size of the cables (three-conductor Clover-Leaf type) must be first determined.

$$\text{Total current per phase} = .58 \times \frac{11190000}{10,600} = 612 \text{ amperes.}$$

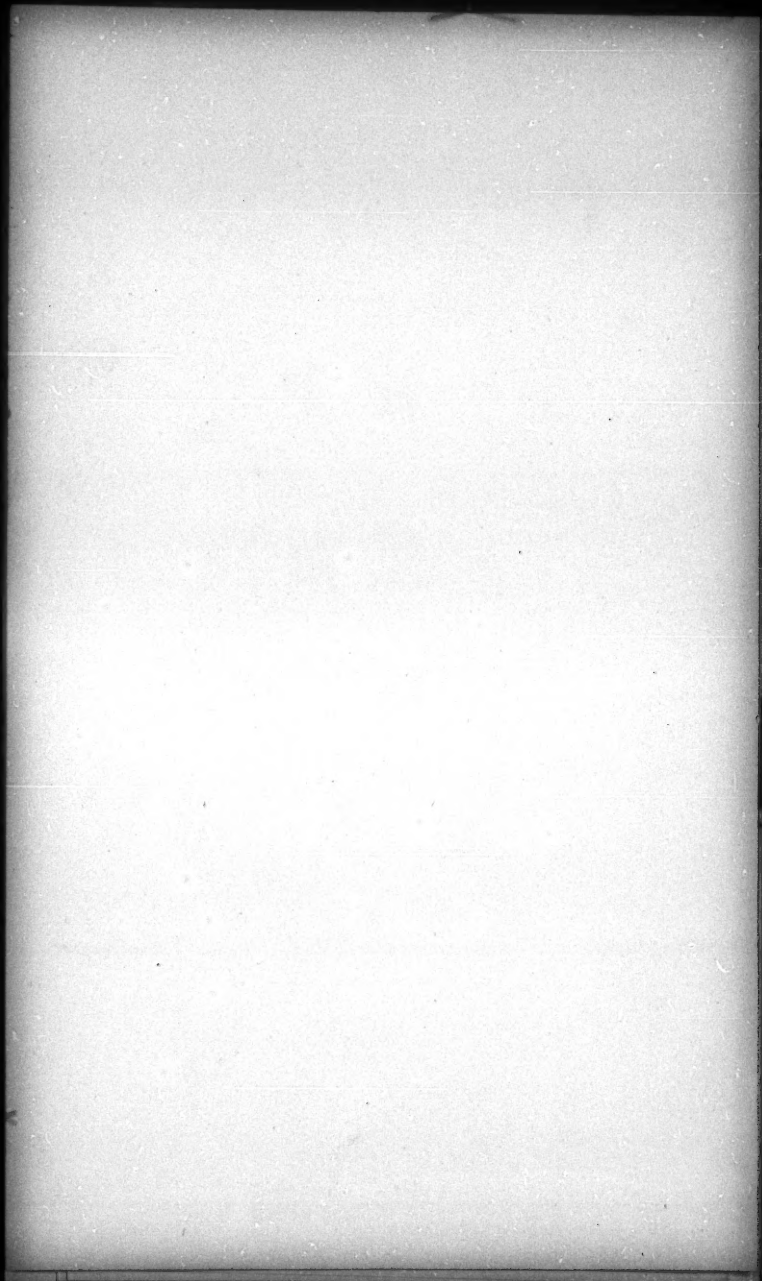
Using six three-conductor cables, the current per conductor = $612 \div 6 = 102$ amperes.

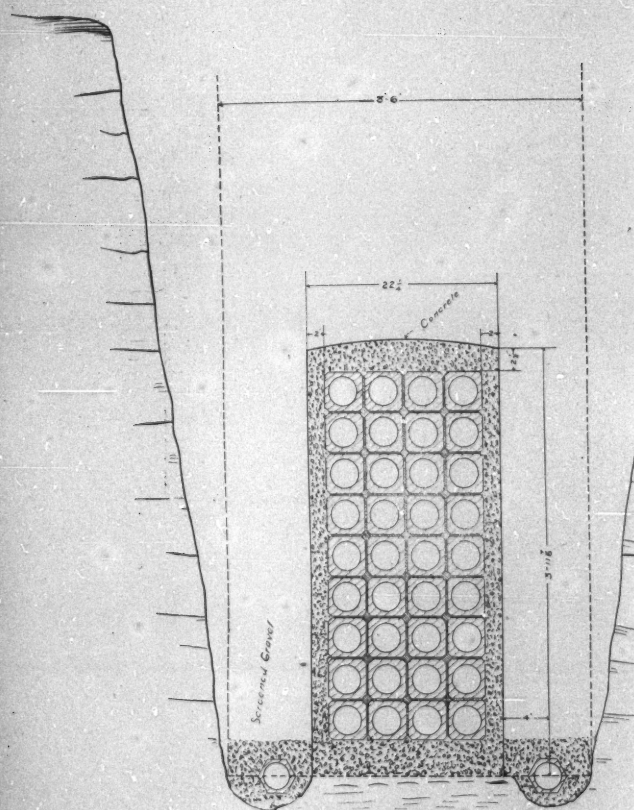
At a temperature of 150° F., using No. 000 conductors, the loss per conductor per foot = $102^2 \times .000075 = .78$ watts.

The loss per cable per foot = $3 \times .78 = 2.34$ watts.

The total loss in cables = $6 \times 11,500 \times 2.34 \text{ watts} = 161 \text{ k. w.}$

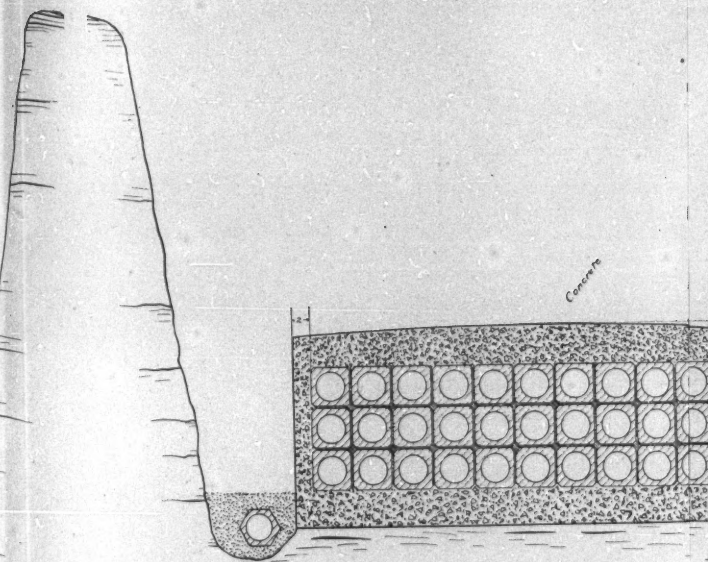
The above is based upon triple conductor cables, each conductor having a section of 167,800 c. m. The loss per duct foot (with this type of cable there is no danger of additional loss in lead) is very moderate, and the maximum temperature will be well within safe limits. As regards limitations due to heat, therefore (and also as regards the application of Kelvin's law of economy), it





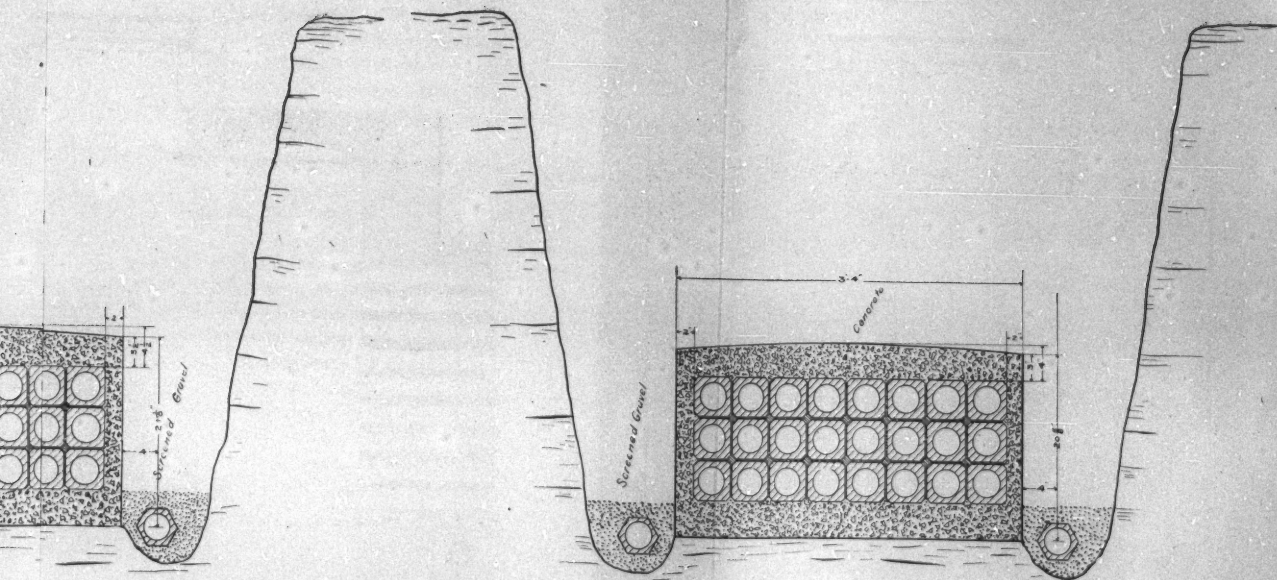
SECTION-A

FIG. 17.



SECTION-B

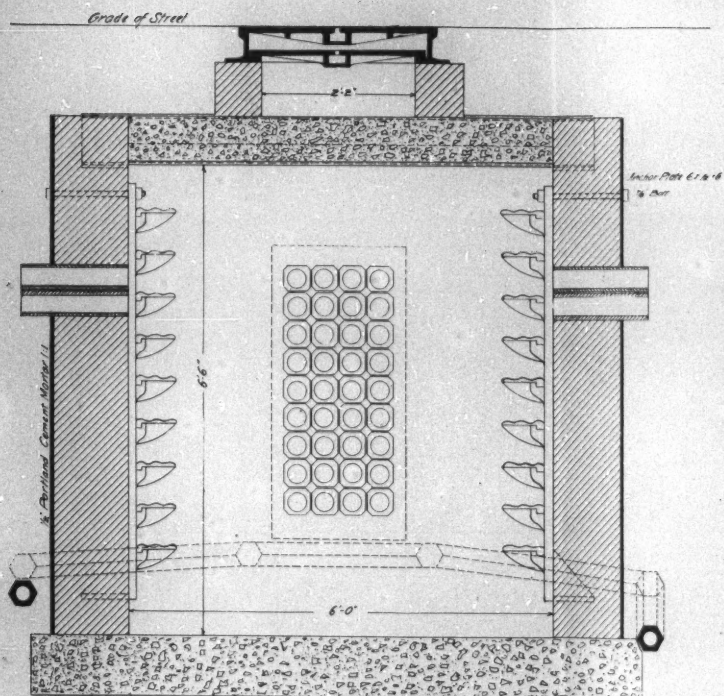
FIG. 18.



SECTION - C

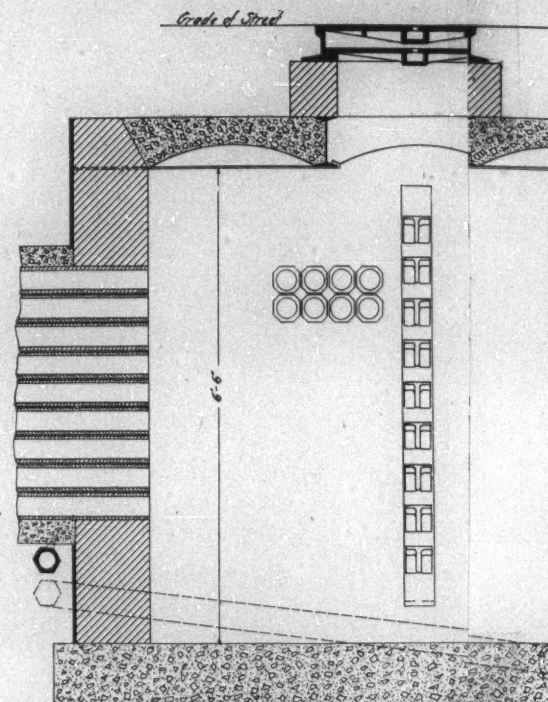
FIG. 19.

OVER



SECTION ON C-D.

FIG. 20.



SECTION ON A-A

FIG. 21.

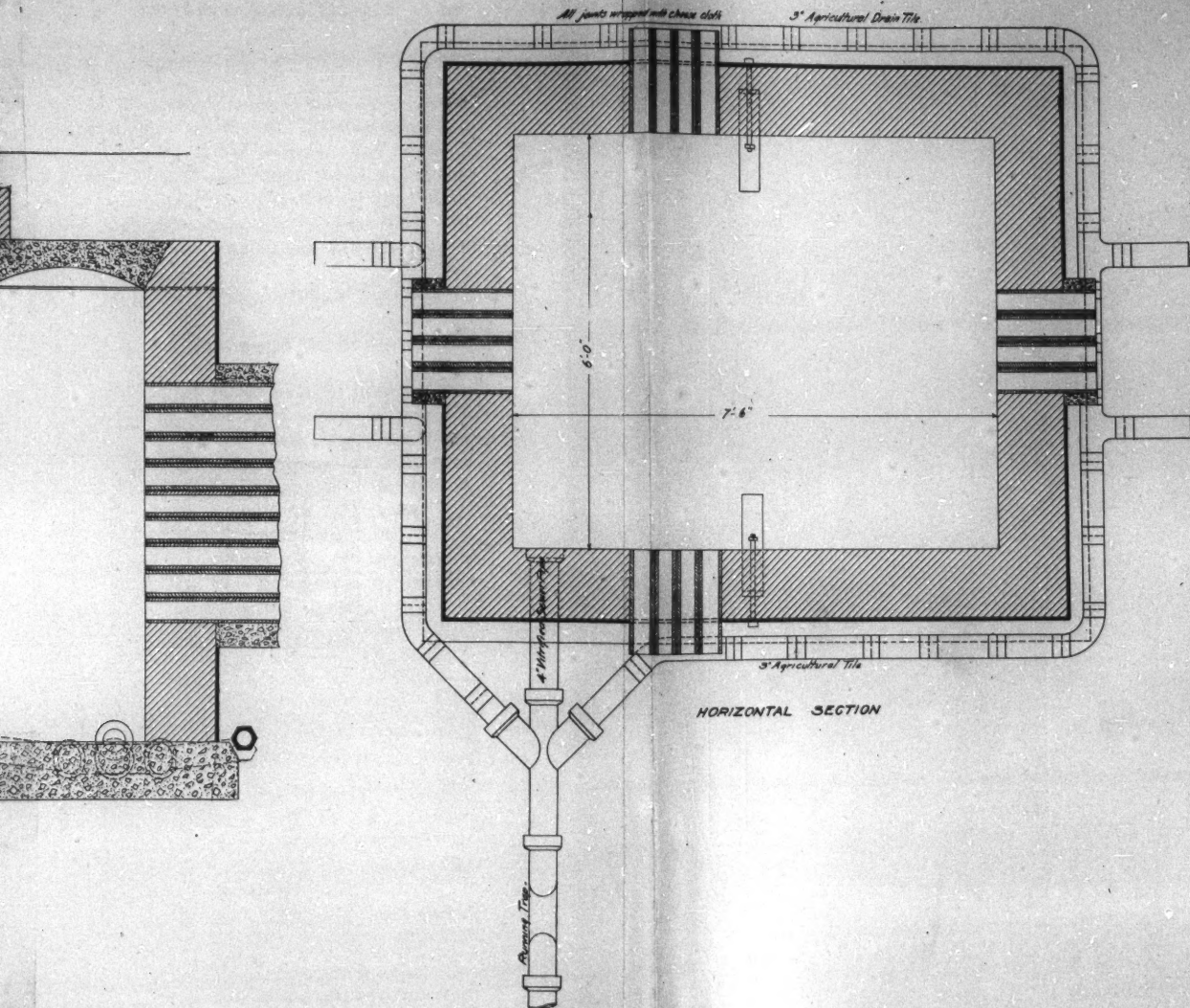
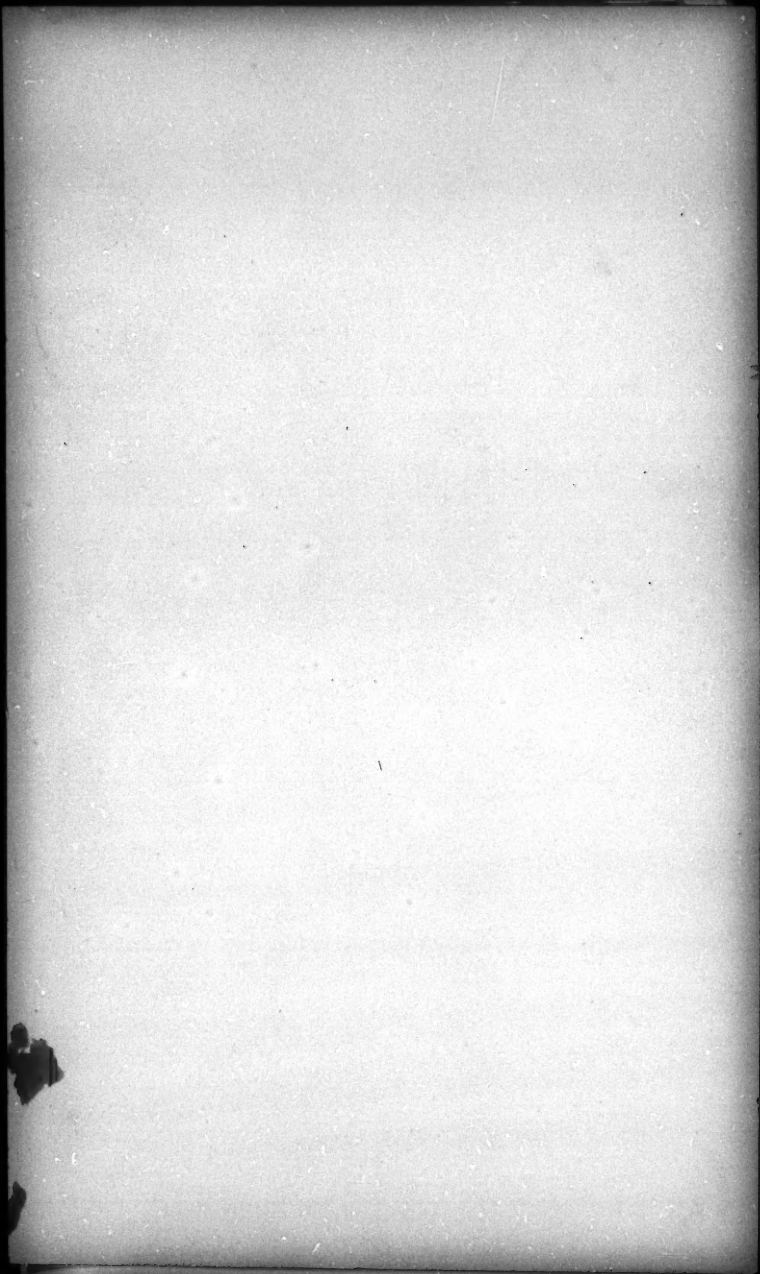


FIG. 22.



would be possible to use conductors of a somewhat smaller section."

Where the sewers are at sufficient depth to drain the ducts the section adopted is that shown in Fig. 17. At other points the sections shown in Fig. 18 and Fig. 19 are used. The former is decidedly preferable as regards arrangement of cables in the man-holes, since with it the natural arrangement is to carry them in pairs on brackets on opposite sides, and for large cables two upon a bracket are much more conveniently handled than a larger number.

It will be noted that no duct in the conduit, as illustrated in Figs. 17, 18 and 19, is separated from the surrounding earth by more than one other duct. Figs. 20, 21, 22 and 23 illustrate the manhole construction adopted.

Bearing of the decision to use 10,000 volts for local distribution to distances exceeding two miles upon question of potential originally chosen for the alternators.—The decision to use 10,000 volts for local distribution at distances exceeding two miles from the power-house is in no way inconsistent with the decision reached in 1893 to wind the alternators for 2,200 volts. The alternator potential was chosen with reference, primarily, to the expected large use of induction motors without the interposition of step-down transformers. In a letter addressed to the Cataract Construction Company, September 30, 1893, I said:

"In the plan which we presented to your company in February last, we recommended a potential of 800 volts. The limit, under the assumptions which we then made as to the use of a large proportion of small motors, was selected because we believed it to be as high a potential as could safely be delivered to the armatures of motors without the interposition of step-down transformers. As we are now informed, it appears probable that the proportion of motors of less than 25 H. P. output will be very considerably less than we then supposed it would be and we are now, therefore, prepared to recommend a potential of 2,000 volts at the motors, believing that this can safely and conveniently be managed."

In my memoir of February 6, 1893, upon this point, the language used was as follows—referring to 800 volts:

"This potential is well adapted to a large part of your work in Cataract City. At a certain distance from the generating station, depending upon the cost of apparatus, cost of distributing circuits and the loss in these circuits, transmission direct from generators at 800 volts will become more expensive than transmission by raising and reducing transformers in connection with

circuits carrying higher potential at this distance which until the cost of apparatus can be settled cannot be accurately determined; we should begin to use raising and reducing transformers in connection with a high potential in transmission circuits."

My object in introducing these quotations from the record is to anticipate and meet the opinion which I have no doubt will be held by certain theoretical engineers experienced in the art of constructing large power plants on paper to the effect that we erred in originally winding the alternators for 2,000 volts instead of 10,000 volts.

Transmission to Buffalo, Tonawanda and Lockport.—For transmission to Buffalo, as I have above pointed out, the subway, or tunnel construction originally suggested by the International Commission was deemed impracticable, and the company ultimately decided to erect overhead lines for transmitting power to that city and to other distant places.

The first pole line was constructed by Messrs. J. G. White and Company, and has been fully described by Mr. White in a paper read before the National Electric Light Association in June, 1897. The poles are of Canada white cedar, cut with sap in and squared at both ends. They vary in length from 35 to 55 feet, the longer poles being used at points where the line crosses railway tracks or public roads. They are set in the ground to depths varying from 6 to 8 feet, the depth of setting depending upon the length of the pole. The cross arms are of selected long leaf Georgia pine. They are 12 feet long and 4 in. x 6 in. in section. The poles are spaced about 70 feet apart except on moderate curves, where they are somewhat closer. In crossing streams and where the curves in the line are at all sharp, braced structures, consisting of two poles set about 22 feet apart and carrying instead of cross arms a horizontal cross piece of heavy timber, 4 in. x 14 in. are substituted.

This pole line was designed to carry 12 conductors of 350,000 c.m. section. Only six of these conductors, constituting two three-phase circuits, have been erected, and the three conductors of each of these two circuits were originally placed side by side on the upper cross arm. This of course located the three conductors of a circuit on the same horizontal plane. The distance between the central conductor and each of the two other conductors was 18 inches. The conductors of each circuit are spiralled in six sections to avoid unbalancing of potential due to

self-induction. As a protection against lightning, a barbed iron wire of the kind extensively used for fencing cattle ranges in the West was carried upon an iron pin near each end of the upper cross arm, this wire being grounded at every fifth pole.

Porcelain insulators of two types, designated, respectively, the Niagara type and Type "C" were used. The pins are of locust. A section of the Type "C" insulator and pin is shown at the right in Fig. 26. The conductors are copper, having 19 strands, and weigh a little more than one pound per linear foot. Every insulator used was subjected to a puncture test of 40,000 volts, alternating, before it was put in place. The method of test is as follows: The insula-

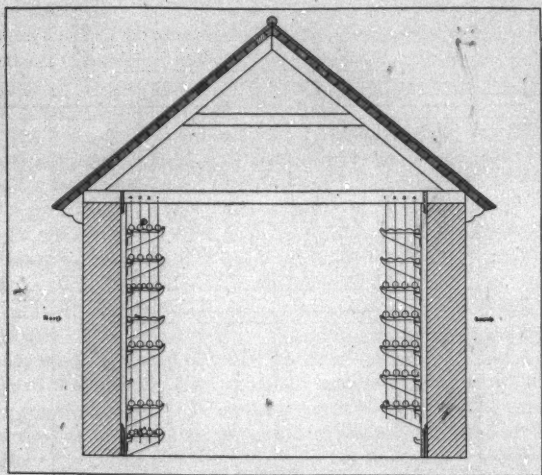


FIG. 24.

tors are inverted and set in a hollow iron pan which is filled with salt water to a depth of two inches. A small quantity of the salt water is poured into the pin hole of each insulator and a small metallic rod is placed vertically in the pin hole where it of course makes good contact with the brine. One pole of the alternating potential is connected to the metal rod, while the other is connected to the pan. Any weakness of the insulator is quickly manifested by a series of sparks usually followed by a breakdown

of the insulator and blowing of the fine wire fuse included in the testing circuit.

In service the guard wires caused trouble by breaking and falling upon the charged conductors, thereby grounding and in some instances short-circuiting the latter. While neither snow nor sleet has ever been observed to adhere to the charged conductors, the guard wires of course became heavily loaded with ice, and as they were not sufficiently strong were frequently broken by weight of ice and by wind pressure. Whether they were of any practical value in mitigating the effects of lightning is an open question. I am of the opinion that they were probably of some benefit in that direction, but the interference with continuity of service which resulted from them was intolerable and they were therefore removed during the summer of 1898. Obviously, if guard wires are used either for protection against lightning or to prevent other wires falling across a power circuit, they should be of ample mechanical strength to withstand all strains to which they are liable to be subjected.

Experience also demonstrated that it was a mistake to place the three conductors constituting a circuit on the same horizontal plane and only 18 inches apart as shown at the left in Fig. 27. I may be excused for disclaiming responsibility for this arrangement in view of the fact that in 1894, acting as Electrical Engineer of the Westinghouse Company, I submitted to the Cataract Construction Company elaborate plans and specifications for a transmission line in which the three conductors constituting a circuit were triangled, the sides of the equilateral triangle being 36 inches. These plans were rejected in favor of others and the arrangement actually adopted by the company proved very tempting to mischievous or malicious boys who repeatedly short-circuited the line by throwing across it short pieces of wire which they succeeded in lodging across two or more of the conductors. The resulting short-circuit continued to blaze along the line until the power was cut off at the Falls. The arc always traveled away from the power house. This, I presume, was due to the fact that when the short-circuit occurred the conductors affected between the power house and the point where the short-circuiting wire lay across the line, repelled each other and very possibly, owing to the natural swing of the conductors, were brought more closely together than usual in that part of the span which lay beyond the short-circuiting wire. The arc

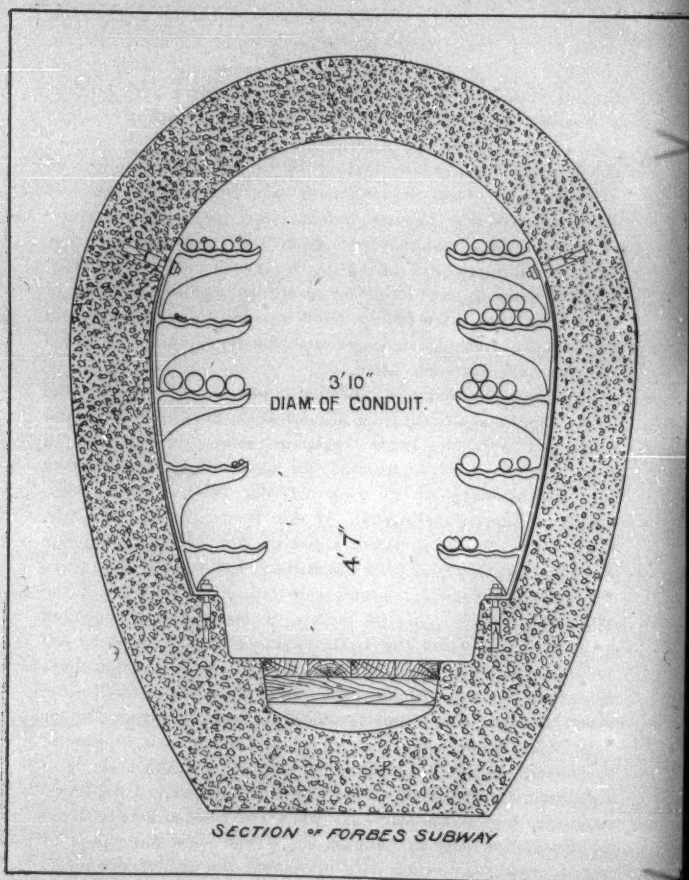


FIG. 25.

caused by the short-circuit was one of great intensity and at night the light was some times seen at distances exceeding half a mile. The conductors were afterward found to be considerably fused and in places little beads of copper projected from the strands. On one or two occasions, in trying to maintain the service and in the hope that the arc would clear itself, power was kept on the lines for some 20 seconds, but on these occasions one or more of the conductors was completely severed. The trouble was finally cured by triangling the wires, bringing them into the position shown at the right of the pole in Fig. 27. You will note that in this method of triangling, two of the conductors are carried on the upper cross arm while the third is carried on the lower cross arm. This arrangement is preferable to the more usual plan of carrying two conductors on the lower and one on the upper cross arm, since it is much more difficult for a mischief-maker to lodge a wire or stick in contact with two conductors.

The first pole line originally extended to a small terminal house located on the banks of the canal, near Albany street, in Buffalo, a point about two miles inside the city limits. In this terminal house the overhead circuits were connected to the cables used to convey currents to the various sub-stations in Buffalo, the apparatus in the terminal house comprising only lightning arresters and single-blade switches for changing connections of overhead and underground lines. These switches were not designed to open the circuits when power was being delivered, but were intended simply to facilitate changes in case of accidents causing interruptions of the service.

In the year 1900 a new terminal house about two miles farther down the river than the old one was erected, and the construction of a second pole line from Niagara was undertaken. The cable system in Buffalo was extended to the new terminal house, and the first two power circuits, designated, respectively, No. 1 and No. 2, which were carried upon the old pole line, were connected to the underground system at this point. It was decided to increase the potential on the overhead transmission lines from 11,000 to 22,000 volts, and as it was deemed impracticable to use 22,000 volts in the underground cables and at the same time was considered desirable to secure electrical separation of the overhead and underground circuits, step-down transformers having a ratio of 22,000 to 11,000 volts were installed in the terminal house. Switching devices providing for connection and disconnection of

the overhead transmission circuits and of the underground cable circuits, together with an elaborate outfit of apparatus intended to protect the transformers against the effects of lightning, were installed.

THE NEW POLE LINE.

The new pole line differs radically from the old one. From Niagara to Tonawanda the length of span is doubled—that is to say, the average span in the new line is about 140 feet as against an average of 70 feet in the old line, these averages in both cases applying to tangents and not to the curved portions of the respective lines. The poles are similar to those used in line No. 1, but every third pole is substantially guyed. The unusually close

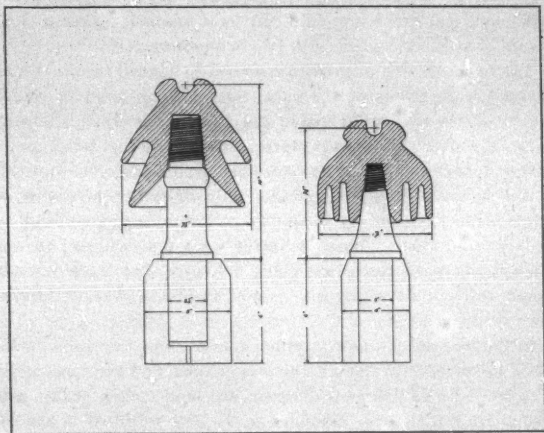


FIG. 26.

spacing of poles in the old line is explained by the fact that it was assumed that during sleet storms ice might cover the conductors to a radial depth of half an inch, which, if it did actually occur, would of course greatly increase the pressure, tending to overthrow the line during wind storms, which upon the Niagara frontier are often very severe. But experience during a number of winters has demonstrated the fact that ice never adheres to the power circuits while they are traversed by the working currents.

This result is due in part presumably to the heating effect of the current and in part perhaps to static repulsion. It is certain that dry snow is statically repelled by the charged conductors, and I think it probable that this effect also helps in the case of sleety rain. In the case of the new line, calculations of the effect of wind pressure were based upon the projected area of poles, cross arms and conductors, but with no allowance for a covering of ice. Experience had shown that mechanically the weak point in the construction of the old line was the junction of pin and insulator, and for the new line a new pin and new insulator were specially designed. Cross sections of the old

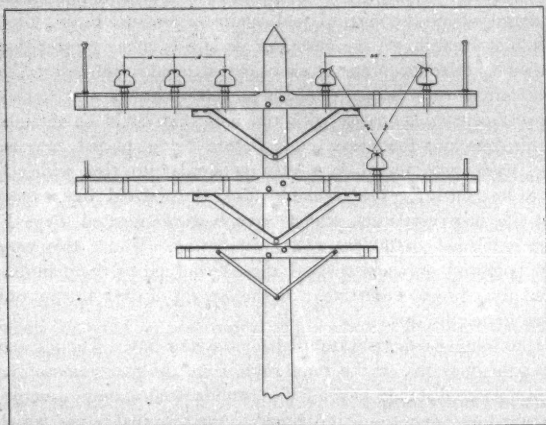


FIG. 27.

and new types are shown in Fig. 26. The old pin at the top is but $\frac{3}{8}$ " in diameter, while the new one is $1\frac{1}{2}$ ". On the old pin but six threads engage with the threads in the pin hole of the insulator while in the new one nine threads are used. It is a singular fact that almost every power circuit hitherto erected in the United States has used an insulator pin of the same diameter at the top as the standard Western Union pin which was designed for a very different kind of service. Without going further into detail, it is sufficient to say that notwithstanding the fact that the length of span is doubled, the insulators

of the new line are relatively much more securely fixed upon their pins than are those of the old line.

Tests were made to determine the horizontal strain which would break pin or insulator or both if exerted at the top of the insulator, *i. e.*, at the point where the pin rests upon the insulator. It was found that a pin will break at the point where it enters the cross arm under a pressure of about 2,100 lbs., which is about six times the calculated maximum pressure to which it will be subjected in service. The shoulder of the insulator will break under a horizontal strain of about 1,300 lbs. in service. The maximum strain upon the shoulder due to wind pressure against the conductor is probably never exerted at an angle of more than 45 degrees from the vertical, and against a pressure in this direction the strength of the insulator saddle is much greater than against a horizontal pressure such as that used in the test. The insulators, as regards quality of the porcelain, show a very marked improvement as compared with the best that could be obtained in this country a few years ago. Before being placed in position, each was tested in a manner similar to that which I have described for the insulators used on the old line, except that the new insulators, which have been designated Type E, were subjected to 60,000 volts, alternating. Under this very high potential, only about 3% of those furnished by the manufacturer proved to be defective. Of the last lot of over 400 not one failed under the test.

Aluminium conductors are used for the new line. The old and new pole lines follow the same route from the power-house to a point a short distance beyond Tonawanda where they diverge, the new line, from the point named to the terminal house, which is located just inside the city line at Buffalo, being approximately three miles shorter than the old lines. Taking into account the difference of the length of the line and in specific conductivity of copper and aluminium, the equivalent section of conductor for the new line works out about 497,000 c.m. The manufacturer guaranteed the conductivity of the aluminium conductor to be not less than 61% by Matthiessen's standard. The impedance of each circuit was calculated, and a section of 500,000 c.m. adopted for the aluminium conductor, which is of course a stranded cable. The line has been in use since April 1, 1901, and when operating in parallel with one of the old lines, the load is so equally divided that no difference can be detected by read-

ings of the indicating wattmeters used. Where the aluminium conductor passes through that part of the company's territory where large chemical industries are established, it is protected by a braided cover treated with asphaltum. The principal reason for choosing aluminium instead of copper was its less cost, the aluminium line at the time when it was ordered costing about 12% less than an equivalent copper line.

In commercial use the line thus far has been eminently successful, not a single instance of an insulator breaking down in service having occurred.

The guaranteed maximum resistance of the conductor is .03472 per thousand feet and the minimum tensile strength is 23,000 lbs. per square inch, with average tensile strength of 25,000 lbs. per square inch. By calculation, with temperature of wire 20° F. below zero, the maximum strain upon the wire will be slightly more than half the minimum tensile strength. In erecting the line the sag was adjusted with reference to temperature of the air at the time of erection in accordance with a table based upon data set forth in the valuable paper upon "The Use of Aluminium Line Wire and Some Constants for Transmission Lines," by F. A. C. Perrine and F. G. Baum, read before this INSTITUTE May 18, 1900.

The joints are spliced and wrapped, but are not soldered. An interesting difference in the behavior of the old and new-lines when the wind is blowing at high velocity has been observed. At such times, the tightly strung copper conductors of the old line swing or vibrate irregularly, but on the whole rapidly, and the strain caused by this vibration is transmitted to the insulators, pins, cross arms and poles in such a manner that the trembling of the pole may be detected by placing the hand against it at a point near the ground. Under similar circumstances, the aluminium conductors tend to assume a fixed position, which is sometimes apparently as much as 45 degrees from the vertical plane in which they hang when the air is quiet. There is practically no vibration perceptible at the pole. The elimination of vibrating strains upon insulator and pin is gratifying, as in the old line the tendency of insulators to work loose from their pins has been noticeable and I have no doubt that it has been caused by the vibration of the conductors during heavy wind storms. In connection with the construction of the new line the high potential connections of the step-up transformer house were radically

changed by all these connections being brought up from an air chamber beneath the transformers, in which they had been placed originally, and supported upon "Type C" insulators carried by a frame work of hard wood and angle iron, as illustrated in Fig. 28.



FIG. 28.

Present Output of the Plant.—In Fig. 29 the load curve for local service and for long distance service, as compiled from half hourly wattmeter readings for the twenty-four hours ending at midnight July 20, 1901, is shown. The local load varies between 14,200 k. w. and 15,700 k. w. This remarkable uniformity of output is explained by the fact that nearly all of the power used

locally is delivered to manufacturing companies whose processes are continuous and whose use of power is practically constant. The long distance load varies from a minimum of 3,300 to a maximum of 15,600 k. w. Of this maximum, probably 90% is used for railway and lighting purposes.

XI. THE ELECTRICAL EQUIPMENT OF THE TERMINAL HOUSE.

Power from Niagara is delivered to the terminal house at present by three overhead circuits, each of which is calculated to deliver the output of two alternators at the Falls, less the losses in step-up transformers and in the transmitting conductors. Two of the transmitting circuits are therefore ample for the present use of power in Buffalo, which does not exceed 14,000 k. w., except for about two hours in the evening, when it rises to nearly 16,000 k. w. The loss in step-up transformers is slightly less than

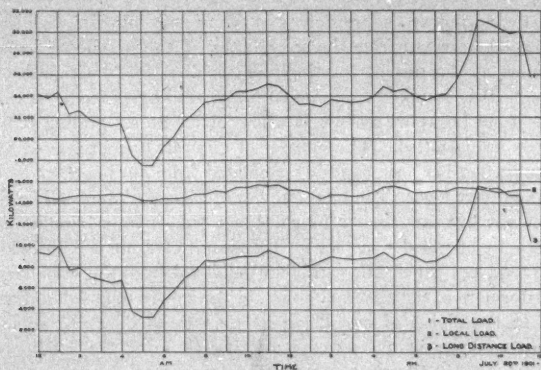


FIG. 29.

2%, and the loss in the transmitting circuits, when two of them are used to deliver the combined output of four alternators working under full rated load, is about 6%. If four alternators at Niagara deliver to the step-up transformers their full rated output, viz., 14,920 k. w., any two of the transmitting circuits operated in parallel will deliver to the step-down transformers at the terminal house about 13,750 k. w. Of this amount the step-down transformers will deliver to cables which convey power to the various sub-stations in Buffalo not less than 13,500 k. w. The net calculated efficiency of the transmission, including losses in step-

up transformers, transmitting circuits and step-down transformers, when two circuits are in use under rated load, is therefore a little above 90%. About three weeks ago I had the pleasure of calling the attention of the President of the Cataract Construction Company to a copy of a letter addressed to him, under date of January 7, 1893, in which, in reply to an inquiry, I had made a statement of the efficiency that could be guaranteed for transmission from Niagara to Buffalo, and of showing him at the same time a letter from Mr. Philip P. Barton, Superintendent of the Niagara Falls Power Company, dated July 15, 1901, giving comparative watt-meter readings at Niagara and Buffalo during June of the present year. The efficiency promised in 1893 under conditions of line loss equivalent to those which actually obtained in operation during June last was 88%. Mr. Barton's letter states: "We have been receiving daily readings of the meters at the terminal house since June 1st. I am therefore able to give you a comparison of the total kilowatt hours delivered from our bus-bars with the kilowatts delivered from the secondaries of the step-down transformers at the distant terminals of the line for the month of June. This is taken from actual meter readings, except for the case of our Lockport tenants, in whose plants no integrating watt-meters are installed. The number of kilowatt hours received by these tenants has been carefully estimated from our knowledge of their average loads. The total number of kilowatt hours delivered from our bus-bars to our long-distance transmission circuits as shown by our feeder meters for the month of June is 6,504,000. The total number of kilowatt hours delivered from the secondary transformers in the terminal house, in the Tonawanda sub-station and in the plants of our Lockport tenants, as shown by actual meter readings in every case, excepting those of the Lockport tenants, is 5,840,100, thus showing a net transmission efficiency of 88.4%." During the month of June the transmitted load was carried sometimes upon one circuit and sometimes upon two circuits. I have calculated the losses in the lines and find that they averaged 6.5%. Of course commercial meters cannot be depended upon for closely accurate reading, but in this case the readings at Niagara were made by 10 meters and at the distant terminals of the line by 12 meters. It may therefore be assumed that errors are averaged, and that the result is probably accurate within 1%. By calculation, with 6.5% line loss, the net efficiency of step-up transformers, line and step-down transformers should be 89.5%.

Calculated results now show higher efficiency than those made in 1893, simply because the actual efficiency of the transformers is higher than that assumed at the time named. The very close agreement of calculated and measured efficiency will not be surprising to members of this INSTITUTE, but may be useful in answering the question often asked, whether results based upon electrical calculations are realized in practice.

The power, which is delivered by overhead lines to the terminal house of 22,000 volts, is reduced in potential and delivered to underground cables at 11,000 volts by two groups of transformers connected in delta. The rated output of each transformer is 2,250 kilowatts and three transformers are therefore capable of transforming the full amount of energy which two alternators and eight step-up transformers at the Falls and one transmission circuit can deliver to the terminal house. In operation, all of the alternators used to supply Buffalo service are operated in parallel as are also the transmission circuits used and the two groups of step-down transformers, but in planning the general features of the terminal house installation the possibility of ultimately operating two or three more electrically separated sets of alternators, lines and transformers was kept in mind and the transformer unit was therefore so selected that a group of three correspond in output to one transmission circuit. In approximate figures 7,500 kilowatts (10,000 H. P. delivered in Buffalo call for two alternators, eight step-up transformers, one transmission circuit and three step-down transformers.

To light a city of nearly 500,000 inhabitants, to supply power for the entire street railway service of that city, to deliver an aggregate of many thousands of horse power used for a very great variety of purposes and at points scattered throughout a territory some eight miles long and four miles wide, to do all this by a system of underground cables which in turn receive their supply through overhead lines exposed to lightning, to the winter storms of the Niagara frontier and to wanton interference of mischief-makers, and under these circumstances to secure a delivery of power free from all interruptions and in every way satisfactory to the users, is by no means an easy task. The theorist may say, get rid of your overhead lines and construct a tunnel or subway, but this, as I have pointed out, is a commercial, if not an engineering impossibility, owing to its great cost, at least until the aggregate use of power in Buffalo becomes so

large that the cost of the underground construction will no longer add to the cost of power at Niagara an amount so great as to render its cost in Buffalo commercially prohibitive. The practical man may say, "You are attempting an impossibility; it is not reasonable to expect that you can tie to one central source by electrical connections, sensitive as human nerves, every industry that employs power in Western New York, expose these electric nerves through half their length to lightning and storm, expose them again in half a dozen sub-stations in complicated switch gear to the manipulation of a large number of attendants and then expect to get along without frequent attacks of temporary paralysis." But if such a view be accepted, progress is impossible. It must be frankly admitted that up to the present time the results of efforts put forth to make the service absolutely continuous and reliable have not been entirely satisfactory, but the creation of a system that shall in a perfectly satisfactory manner distribute throughout a territory so extensive and so complex in its requirements the surplus power of the Falls is necessarily an evolution requiring time. Very substantial progress has been made; apparently not many difficulties remain to be surmounted.

The equipment of the terminal house by the Cataract Power and Conduit Company will make it possible to introduce improvements in the system of distribution in Buffalo which may be reasonably expected to eliminate certain causes of trouble.

The system of distribution in Buffalo has been recently described in a very able paper¹ read before the INSTITUTE by Mr. H. G. Stott, and I shall not attempt to describe it here. With the terminal house equipped, the supply of power to sub-stations in Buffalo presents to the Cataract Power and Conduit Co. exactly the same problems that would have to be met were a central power house using steam driven alternators substituted for the terminal house, except that on the Niagara side of the 10,000-volt bus-bars, step-down transformers, transmission circuits and the power plant at Niagara take the place of the alternators and steam plant.

The local system of distribution at Niagara is probably as perfect as any in existence and there is every reason to expect that when the extensions and alterations in the cable system and in switch gear at sub-stations, which are now made possible by

1, TRANSACTIONS. vol. 18, No. 4. 1901.

the installation of the terminal house equipment, are completed, the distribution of power in Buffalo will be thoroughly satisfactory to all concerned.

At the terminal house, the protection of step-down transformers against the effects of lightning is extremely important and not altogether easy to accomplish. The apparatus installed for the purpose comprises lightning arresters, reactance coils and a new device which the Westinghouse Company has recently developed and designated by the name "static interrupter." The lightning arresters proper comprise spark gaps between Wurts non-arcing metal cylinders in conjunction with the usual ground wires and plates, but the arrangement of the spark gaps differs materially from that generally used hitherto, a non-inductive resistance being used in series with all of the gaps while a part of the gaps are shunted by a non-inductive resistance. This apparatus, which has been designated the "low-equivalent lightning arrester," has been fully described in a circular issued by the company referred to.

It seems reasonable to expect that the separation of overhead and underground lines by interposition of step-down transformers in the terminal house will obviate some of the difficulties which have hitherto resulted probably from the metallic connection of overhead and underground circuits. That the lightning arrester equipments at Niagara and at the terminal house are effective is evidenced by the fact that no transformer at either point has ever been damaged by lightning, although on several occasions the line has been struck so heavily that cross arms and even poles have been shattered.

XII. THE EQUIPMENT OF POWER-HOUSE No. 2.

I do not propose to discuss in detail in this paper the electrical equipment now in course of construction in power-house No. 2. Shortly after preparing the general specifications for that equipment, I resigned my position as Electrical Director of the Niagara Falls Power Company to give attention to other enterprises. The company has been fortunate in securing the services of Mr. H. W. Buck as Electrical Engineer in charge of new electrical construction, and it is to be hoped that when the new plant is installed, he will describe in detail for the benefit of the INSTITUTE the modifications introduced as a result of experience and the results realized therefrom. Meanwhile, how-

ever, without impropriety and without trenching upon the province of those upon whom will rest the responsibility of carrying out the plans thus far determined, and extending them to meet the requirements of future growth, I may outline briefly the more important features with respect to which the equipment of power-house No. 2 will differ from that of power-house No. 1.

The general organization of the equipment will differ in having all switch gear and measuring instruments located in one structure instead of in two separate structures. The ultimate equipment will comprise eleven 3730 kilowatt alternators, wound for two-phases and 2200 volts. Oil switches operated by electric motors in combination with spring mechanism will be used. The cable subway, which, in power-house No. 2 as in power-house No. 1 is parallel to the row of alternators, will be widened to an extent sufficient to permit installation of all bus-bars and connections except the vertical risers to the switches below the floor line of the power-house. Above the floor line and directly over the subway which is opposite the middle of the row of 11 alternators the switches will be placed in brick compartments, faced on the outside with white enameled brick. As in power-house No. 1, two sets of bus-bars will be used. The circuit from alternators to bus-bars passes first through a circuit-breaking switch with time-limit overload attachment and thence to terminals of a pair of oil circuit-breaking switches, non-automatic, by means of which connection is made to either or both sets of bus-bars. Pairs of switches similarly arranged are used for each feeder circuit, but these are automatic with time overload attachment. All switches are of the new type developed by the General Electric Company, in which the circuit is broken under oil, the four sets of terminals of each switch being enclosed in separate brick compartments.

Instead of instrument stands, a switchboard of blue Vermont marble, located upon an elevated platform about the middle of the power house, will be used to mount the indicating and measuring instruments. Below these instruments, and extending the entire length of the board, a distance of 70 feet, the small switches which electrically control the movements of the large switches in the alternating current circuits will be located and these will be assembled in connection with an organization of dummy bus-bars and connections in such a way as to constitute an exact diagrammatic representation of the actual existing

connections of the power circuits. While the organization of switchboard apparatus in power house No. 1 is remarkably free from complication, experience in the operation of the plant has demonstrated the fact that in time of emergency the most skilful operator is liable to make mistakes. When something goes wrong, the operator has no time to draw diagrams nor even to think diagrams. At such times the eye is a quicker and more certain guide than the mind. I feel confident that the use of the diagrammatic operating switchboard arrangement will materially contribute to the safety and certainty of operation.

The regulation of the alternators will be much closer than that in the machines thus far installed. Their external appearance will be considerably changed by the removal of the bridges, this being made possible by locating the field collector rings on the shaft below the stationary armature and carrying the exciting current to the field by wires placed inside the hollow shaft. Some changes in the armature winding, aiming particularly to secure greater mechanical rigidity, have been made and the design adopted provides also for a change in the system of internal ventilation.

In other respects, the new alternators will not differ materially from the old ones.

As in the case of power house No. 1, exciting current will be supplied by continuous current machines driven by turbines, but in the case of power house No. 2 these will be located in chambers excavated in the sides of the wheel pit at the level of the turbine deck. Experience has shown that similar chambers in the old wheel pit are almost perfectly dry, and it is thought that the simplification of the hydraulic plant required to drive the exciters, which results from placing them near the bottom of the wheel pit, will reduce chances of possible interruption of service by reason of trouble with the exciter turbines and shafts.

I began this paper by saying that "The history of the Niagara Falls power plant is a demonstration of the ability of applied electrical engineering science to attain in commercial practice results predicated in large degree upon theory." What are the practical results thus far attained?

Briefly, the Niagara plant has contributed in no small degree to the development of a considerable number of important chemical industries, and is already the center of a prosperous and

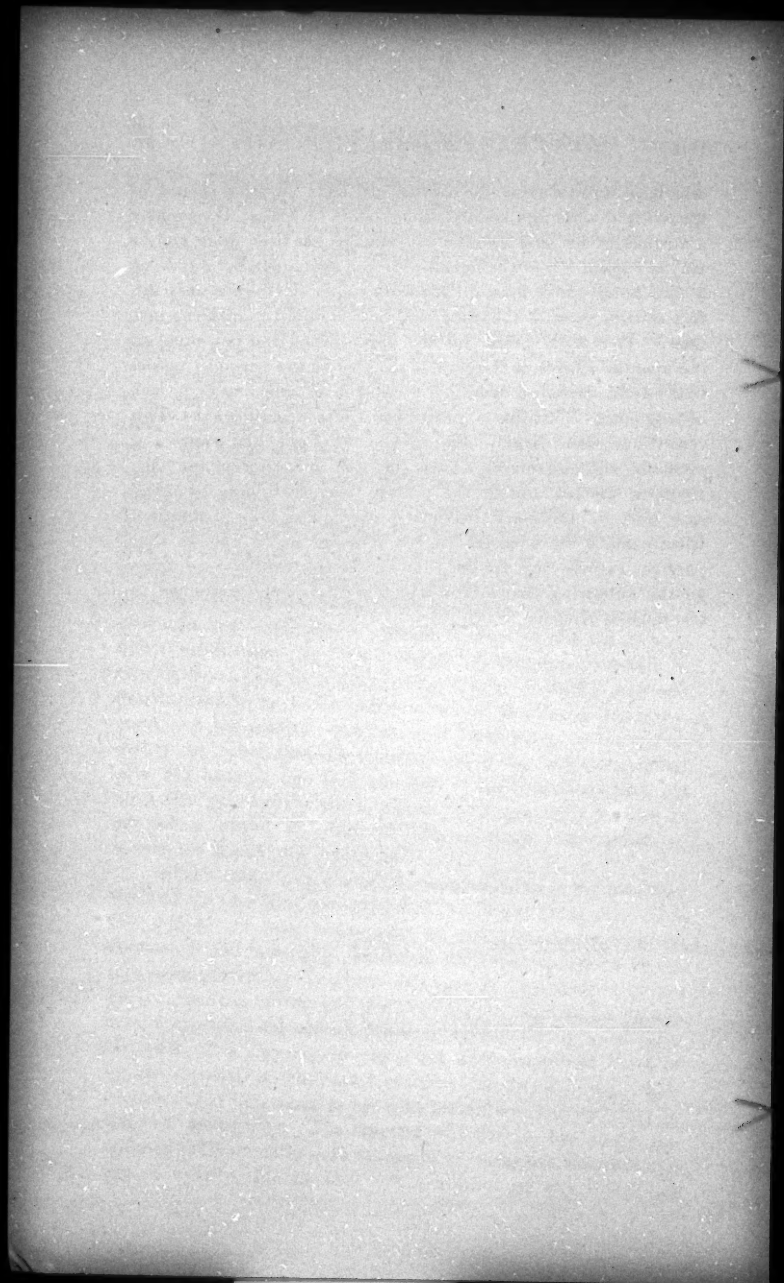
rapidly growing manufacturing community. It is lighting Buffalo, Tonawanda, Lockport, and Niagara Falls, and is operating the electric railway systems in the cities and towns named.

For the first six months of the current year, the output of the plant was 104,378,000 kilowatt hours. A steam driven plant delivering the same output and using three pounds of coal per unit at the switchboard, would have burned in the time named 156,000 net tons of coal—more than 800 tons per diem.

The generating plant, including alternators, exciters and switch gear has been remarkably successful and satisfactory in operation. The cost of maintenance and repairs for the past two years has been less than one per cent., while maintenance and repair of the motive power plant, including turbines, governors, pen-stocks, shafts, inlet racks, etc., has approximated two per cent. The local distributing system also has proved satisfactory in service. The long distance transmission and distribution of power hitherto has been subjected to occasional interruptions, brief in duration but nevertheless seriously annoying. The separation of overhead and underground circuits effected by the use of step-down transformers in the terminal house, improvements in organization of the local distributing system in Buffalo now rendered possible by the installation of the terminal house equipment and the gradual elimination of weak points in the system justify the belief that the interruptions of the long distance service will become less frequent than in the immediate past, but until the time arrives when it shall be commercially feasible to use cables instead of overhead lines occasional interruptions of service are apparently inevitable.

I cannot close this paper without referring to the excellent work of the operating department of the Power Company. It is not difficult to plan upon paper an extensive system of interconnected and mutually dependent electrical apparatus which will work perfectly—on paper—but such an organization of apparatus realized in iron and steel and copper requires for its successful operation the utmost degree of systematic vigilance upon the part of a thoroughly organized and disciplined force of trained operatives who must not only be familiar with their routine duties but ready to act with promptness and certainty in time of emergency. The theorist who sits in his study, examining diagrammatic connections of an extensive electrical system, is usually able to work out a solution of any difficulties

which he may imagine—he can see just what switches should be thrown and what new combinations should be made; if he makes a mistake in his first solution no damage has been done, and he may try again. But the operator on the switchboard controlling 50,000 horse power must do his work under conditions very different from those of the study, and he can afford to make no mistakes. It is high praise for the organization and personnel of the operating force at Niagara to say that of the various troubles that have occurred in operation those due to mistakes or to lack of vigilance constitute a proportion quite insignificant. This result has been largely due to the foresight and systematic methods and organizing ability of the Superintendent, Mr. Philip P. Barton, and to the prompt resourcefulness, technical skill and extraordinary coolness in emergency of the Resident Electrician, P. M. Lincoln. It is a pleasure to be able to thus publicly express my appreciation of the able assistance of these gentlemen during the years in which we have been associated in the work at Niagara.



*A paper presented at the 18th Annual Convention of
the American Institute of Electrical Engineers,
Buffalo, August 24th, 1901, President Stein-
mets in the Chair.*

NOTES ON MODERN ELECTRIC RAILWAY PRACTICE.

BY ALBERT H. ARMSTRONG.

During the past few years electric traction work has been passing through a transition period, outgrowing the restricted limits of city surface traffic and encroaching upon a class of work hitherto accomplished with the steam locomotive. The broadening of the electric traction field has necessitated considerable development in the motive power, and the transmission and conversion of electrical energy, and it is the purpose of this paper to briefly review some of the more important problems in electrical traction now in course of installation or under serious discussion.

The first case to be considered is the small city railway where 500-volt direct current generation and distribution amply suffices. As the system grows and the demand for suburban service increases, it becomes necessary to install either a large amount of feeder copper, a booster, or a storage battery. All of these expedients to take care of the suburban load are temporary, however, as they do not possess inherent qualifications sufficient to care for a rapidly growing system. There is a limit to the amount of feeder copper that can be economically installed; the booster if used continuously brings the coal consumption up to a prohibitive figure; and the storage battery is not adapted for an expanding system, and furthermore cannot successfully take care of long sustained overloads at the end of a suburban line fed from a city system.

Transmitting energy by alternating current affords a means of feeding a large territory from a single generating station, but in the case of a small city road the amount of alternating current required is a small proportion of the total generating station capacity, the bulk of which calls for 500-volt direct current. The best method of meeting this demand for suburban service is therefore to install in the d. c. generating station a standard rotary converter operated from the d. c. bus bars as an inverted machine, and feeding a similar machine at the objective point by means of step-up and step-down transformers. The advantage of this method of generation is that both machines may be used as converters later on when the suburban load has increased sufficiently to warrant the installation of alternating current generators, replacing the direct current machines in the city station. Double current generators may be used, furnishing direct current for local consumption and alternating current for distribution purposes, but the installation of such machines presupposes that the ultimate load will be approximately evenly divided between the d. c. and a. c. output. It is probable, however, that the a. c. output will increase in a much faster ratio than the d. c. with its restricted area of distribution, so that double current machines do not afford the same convenience for taking care of future growth as do standard alternating current generators furnishing alternating current only.

The direct current system of generation, even for city distribution, becomes greatly handicapped with the continued growth of the city, owing to the large amount of power to be transmitted and the wide area which the city covers with its probable efficient street car service, thus relieving congestion in the center of the city. The alternating current generating station with substations scattered throughout the city appears to be the trend of the city distributing systems even where suburban connections do not exist, and where such suburban extensions do exist, all arguments point still more to the alternating current as the proper method of generating and distributing railway power.

One great advantage of the alternating current lies in its affording a means of consolidating adjacent roads under one system of generation and distribution; indeed, the alternating current is a prime factor in such consolidations, as it effects a large saving in operating expenses by doing away with the many

small direct current stations required with the local 500 volt d. c. power-house.

The above discussion considers primarily the city surface road with suburban extensions running at moderate speed and operating cars of moderate weight, say, fifteen to eighteen tons. The growth of such a system in this country has been, first, the installation of d. c. operating apparatus, then the motor or engine driven booster, followed by the inverted rotary converter with alternating transmission, and finally, as the system expands, a large generating station containing high-tension alternating apparatus with several rotary converter substations suitably located to take care of the various parts of the system.

There is another class of railroads which differs in many points from the ordinary city lines, and included in this list are the elevated and underground rapid transit roads. The problem presented here is the operation of trains of two to six cars, weighing from 50 to 150 tons, at schedule speeds ranging from 13 to 16 miles per hour, with stops averaging from three down to two per mile. These roads operate on private right of way, stopping at designated stopping points, and are not influenced in any way by the surface traffic of the city streets.

The motive power to operate these trains at high schedule speeds and with frequent stops must be so designed that it can give an enormous torque during acceleration, and the controlling apparatus must provide for the efficient handling of these motors during fractional speed running. The problem becomes one of carefully determining the proper motor characteristics for efficient acceleration, and a proper motor design so that unsafe temperatures will not be reached from repeated temporary overloading of the motors.

Direct current has been generally used for such work, while the system of transmitting the electrical energy is in a transition period, but gradually changing over in the older installations and being installed in the newer installations as alternating current generation with rotary converter substations operating at 600-volts d. c. The reasons are the same as those influencing the change of the generating stations operating surface lines—the inability of a single direct current generating station to feed the large systems in operation with a reasonable amount of feeder copper, and the reduction in operating expenses resulting from replacing several d. c. stations with a single a. c. station well located.

The d. c. series motor seems particularly well adapted for the propulsion of rapid transit trains running at variable speeds. Of the total input to the train, a properly designed motor equipment will give out over 70 per cent. as useful work at the car wheels—that is, all the losses occurring in the motors and in the controlling apparatus are less than 30 per cent. of the total energy input to the train. Where the runs are longer, and the train is permitted to run for some distance at full speed, the losses are of course considerably less; but even with the frequency of stops ruling in our elevated roads, the “efficiency of acceleration,” so-called, is very high. This high efficiency of acceleration is due to the fact that direct current series motors can accomplish a considerable part of the acceleration of a train on the motor curve with starting resistances entirely cut out and motors operating with full line potential. This part of the acceleration curve may be made at an efficiency of over 85 per cent., thus making up for the starting resistance losses while the motors are running at fractional voltage. In making the above efficiencies of acceleration it is understood that the series parallel controller is used. A slightly better efficiency of acceleration is obtained by a series parallel controller provided for starting with four motors in series, changing to two in series, then all in multiple; but the complication of this controller is not warranted by the one or two per cent. higher efficiency obtained with it.

Elevated and rapid transit roads within the cities are built along the following lines: A single alternating current generating station well located with respect to cheap fuel and water, a transmission line consisting of underground triple lead-covered cables leading to substations suitably located with regard to the load, and operating at 600-volts d. c., a d. c. distribution system consisting of third rail and track return with feeders of either copper or rail, if required, and finally direct current series motors mounted either upon a locomotive or motor car, and controlled by a single controller or distributed throughout the train and controlled from a system of train control.

There is a new class of railways which is becoming the center of great attention. These are high speed interurban, or cross country lines of considerable extent. These lines operate on private right of way, are carefully graded, have few sharp curves and operate cars weighing from 30 to 40 tons at schedule speeds as high as 40 miles per hour, including stops at every three

miles or more. These roads are paralleling the steam roads and make the same schedule speed as the steam roads provide, with the additional benefit of more frequent stops. Owing to the great tractive effort provided with motors connected to each axle, trains electrically driven can accelerate much faster and hence maintain the same schedule with more frequent stops than it is possible to accomplish with steam locomotives.

These interurban lines operate their cars through the city streets at the termini, thus picking up and discharging passengers at the most objective points and thereby making them still keener competitors of the steam railway systems. Owing to the high speed of these heavy suburban cars and the necessity for fairly rapid acceleration, each car or train unit will demand a considerable current when starting up. This current may reach 400 to 600 amperes per car, falling to 150 to 200 amperes per car when running at constant speed of 50 miles per hour, or more. Some interurban roads are being installed contemplating a maximum speed of nearly 70 miles per hour, so it is evident that the motors as well as the distributing system must be so designed that they can take care of enormous fluctuations in load. As these interurban systems are now being installed with 100 miles or more of track, the advantage of alternating current distribution at high potential is evident, and this method of distribution is universally used. Substations are located at intervals of ten to fifteen miles, and may or may not be equipped with storage battery auxiliaries. The storage battery effects a more uniform load curve on each individual substation, but the effect of such storage battery auxiliaries upon the generating station load curve may be quite small, due to the number of substations fed from a single generating station. A single alternating current generating station operating at 26,000 volts can feed the territory lying within 50 miles radius of the power-house, and the load thus secured, although violently fluctuating at the individual substations, is greatly smoothed out when the resultant load of the several substations is read upon the generating station bus bars.

In interurban work the direct current series motor shows itself to be capable of taking care of the widely different demands placed upon the motive power. For instance, the cars must be able to run for long distances at full speed with infrequent stops, but must also be capable of operating over city streets at city

schedules with the stops six to ten per mile customary in city work. The series parallel control of motors is of course a considerable help, as it permits half speed running with motors in series, but even this half speed may be too high for city work, thus calling for considerable rheostatic control with motors in series.

Although great care is taken in laying out suburban roads to keep down the grades and eliminate the curves as far as possible, still the grades may be heavier than would be permissible with steam locomotive propulsion, owing to the greater traction provided with electrically propelled cars. The characteristic of the series motor which permits it to slow down on grades, and speed up on levels is therefore very valuable in this kind of service, as it reduces the fluctuations upon both the motive power and the distributing system.

The qualifications of the direct current series motor for inter-urban work have been entered into at some length, as there is another method of electrical distribution coming into notice—alternating generation and transmission, and alternating induction motors upon the cars. The system consists in brief of a multi-phase generating station feeding into transmission wires extending along the line of travel, feeding at frequent intervals into step-down transformers which reduce the transmission potential to a still considerable pressure for the overhead trolleys. Induction motors receive their power directly from these trolleys and are geared to the car axles by the standard method.

A principal advantage of the induction motor system lies in the reduction of the labor account due to the elimination of attendance at the substations, the step-down transformers being self-cooled and requiring no more than casual inspection. Where the train service is infrequent and does not justify the expense of substation attendance every 12 or 15 miles, the induction motor system offers a substitute to the converter system worthy of very careful consideration. As the induction motor system introduces several features which are new, viewed from a direct current standpoint, a few of its characteristics will be touched upon.

The induction motor, while not a synchronous piece of apparatus, is such, so far as its behavior in railway work is concerned. A car equipped with such motors will run at practically constant speed up grade and down, or on level, thus making the

car speed nearly independent of the profile of the road. The speed of the induction motor, depending upon the frequency of the source of supply, is not affected by the voltage, provided the voltage is sufficiently high to provide the torque required. This constant speed quality of the induction motor at first sight appears to be a desirable feature, as it would seem to ensure the maintenance of a constant schedule speed not influenced by grades. The greatest objection, however, is that the practically constant speed of the induction motor car up the severest grades calls for a very large motor output and produces much more violent fluctuations upon the distributing and generating system than is the case with the D. C. series motor, which falls off considerably in speed on heavy grades. The system, being alternating throughout, provides no means of introducing storage batteries to smooth over these excessive fluctuations, and they are more liable to reach the generating station and produce an irregular load curve with its greater coal consumption than is the case with direct current series motors and rotary converter substations, even though this may be used without storage battery auxiliaries. Where the system is so extensive that each individual car or train is a small increment of the total load, this objection of fluctuations upon the generating station will of course not hold true. The motive power, however, must provide for the running of the car or train up the steepest grade at practically the same speed at which the car operates upon a level, and the motors must therefore be designed to stand a greater output for the same service performed than the direct current series motor.

The induction motor can give only a certain maximum torque with a given impressed line voltage, and as this torque decreases with the square of the impressed voltage, it will be necessary to carefully determine the operating conditions of the motor and of the distributing system in order that the motor may be able to start its car or train upon the heaviest grade with the minimum line potential met with in operation. The direct current series motor can give a torque much in excess of any service demand, without sacrificing its running qualities at light loads. Railway service calls for a large overload capacity of its motive power, and the induction motor can meet these infrequent demands only by a design which sacrifices some of its advantages for normal operation. For example, a motor car to be successful must be able to operate through snow storms, occasionally haul a trailer,

or push in a disabled motor car over the irregular profile of the road. An induction motor car designed to provide just sufficient torque to operate itself alone, would fail to give the commercial satisfaction which is given by the direct current series motor car with its capability of standing enormous overloads for a short time. It is evident that the practically synchronous operation and limited torque of induction motors introduce a number of problems into high speed interurban work not met with in direct current distribution, and that the motive power, transformer substations, distributing system and generating system must all be designed very liberally in order to take care of the violent and large fluctuations inherent in the operation of the railway induction motor.

The induction motor, like any piece of alternating apparatus, demands a magnetizing current, and this current is much larger than that met with in stationary motors, due to the larger air-gaps demanded in traction work. Stationary motors can run at air-gaps of but three or four thousandths of an inch, but the railway man would decline to assume the responsibility of keeping up his bearings for any such air-gap. Increasing the air-gap will raise the magnetizing current, lower the power factor of the system, and hence increase the size and cost of the distributing and generating apparatus. The necessity of designing the railway induction motor to meet unusual demands occurring very unfrequently further increases this magnetizing current, due to the high density required in the iron circuit with a reasonable motor weight. Even with a liberal air-gap, viewed from an induction motor standpoint, such a motor demands a clearance between field and armature nearly 50 per cent. less than is common practice with d. c. motors. The maintenance of linings with a small gap is a matter for consideration, particularly when it is remembered that when the armature of an induction motor strikes its field, it may destroy two sets of windings as the field is a duplication of the armature winding. We are therefore confronted with the maintenance of an air-gap of half the width and double the expense of repair with the induction motor to offset the small commutator maintenance of the d. c. motor.

The installation of high-speed interurban roads in this country has been brought about by the financial success of the earlier roads of this character. Because a system is operative is no reason for its adoption unless there is sufficient promise of its

superiority over present methods. Our interurban and suburban roads possess a very strong advantage in being able to traverse city streets en route and at their termini. All the large cities in this country, and most of the smaller ones, have direct current railway systems in operation, and the direct current interurban and suburban system can therefore run its cars over existing city systems without in any way conflicting with the operation of such roads. The induction motor interurban system, on the other hand, would necessitate the changing of cars at the outskirts of the termini cities, running around the cities passed en route, or else the equipment of unused streets with double trolley and alternating current; or as an alternative, changing over the generating and distributing system and motive power of all cities entered, to alternating current. There are a number of engineering difficulties to overcome before such a change would be commercially practical.

A chief advantage of the induction motor system lies in the ability of running motors from trolley potentials far in excess of 600 volts universally used with direct current series motors. Not having any commutator, the induction motor can use trolley potentials of several thousand volts, and proper line insulation and safety in operating, are the only limits placed upon the trolley voltage. Owing to the large lagging currents demanded by induction motor roads which operate at power factors ranging from 50 to 75 per cent., it is desirable to use as high a potential as possible in order to eliminate the excessive feeder copper or frequent transformer substations required with low voltage distribution. A trolley potential, therefore, of 2,000 or 3,000 volts offers advantages in interurban distribution well worth the extra expense and development needed to insulate trolley and car wiring at this comparative high potential. In order that the motive power will be reasonably cheap, and bearing in mind that such motive power must stand maximum demands considerably in excess of the direct current motor, it is advisable to wind the motors directly for the trolley potential rather than introduce the expense and provide space for step-down transformers. We are therefore confronted with the difficulty of running a 3,000-volt trolley through small cities along the route and into large cities at the termini, even assuming that the cost of changing over such systems to alternating current would be justified.

Step-down transformers installed upon the car, reducing from 3,000 to 600 volts, open the possibility of running motors without step-down transformers on city streets, and with step-down transformers when the trolley potential is 3,000 volts in the open country. The double trolley, however, complicates the city system and adds additional expense to the already expensive motor equipment. The induction motor, moreover, is not adapted to city street running, calling as it does for constant acceleration and efficient operation at fractional speeds. Instead of efficiencies of acceleration in the seventies obtained with direct-current motors, the induction motor would give an efficiency of only 40 to 45 per cent. during acceleration with a corresponding increase in coal consumption, making it compare very unfavorably with the direct current motor for city work. The adoption of the induction motor for interurban work seems limited, therefore, to those roads running on private right of way throughout, and having no connection with existing city systems at their termini or en route. Even in this class of roads, if the service is at all frequent and profile very irregular, the direct converter system with its third rail distribution may prove cheaper to install and operate. The reduction in operating expenses which the induction motor effects by dispensing with rotary converter sub-station attendants may be more than offset by introducing apparatus whose volt-ampere capacity may be double the k. w. capacity required, and which furthermore may operate with a very irregular and inefficient load curve as compared with the load curve produced with d. c. series motors.

The writer has endeavored above to bring out a few of the obstacles in the way of the success of the induction motor for general interurban work. There are, of course, special instances where the roadbed is practically level, grades and curves being eliminated and the conditions ideal for the installation of induction railway motors. It is unfortunate, however, that all interurban roads cannot pick out a level country, or have unlimited capital at the back of them in order to provide ideal conditions for the motive power. In fact, the motive power must accommodate itself to the physical limitations of the road, and it is just here that the direct current series motor shows its superiority to the induction motor where the profile is irregular and where the service consists of mixed city, suburban, and interurban high-speed work. As before stated, interurban high-speed roads are

being rapidly extended in this country owing to their economic success, and in a large number of cases coming under the writer's observation, the induction motor could not compete in first cost of installation, nor in expense of operating with the d. c. motor, operated from rotary converter substations and high-tension alternating transmission. The expense of the few men required to operate substations is a very small item in the total operating expenses of the road, and as our interurban roads more nearly approach steam practice, they require attendants every 10 or 15 miles to serve as ticket agents, train dispatchers, etc., so that with a well-organized interurban system, the item of substation attendance can be largely charged to the general operation of the road and not to the cost of producing power.

The ideal conditions for the operation of induction railway motors seem to be a regular profile, either level or a uniform up-grade, private right of way with no city or suburban running, infrequent service, and freedom from unexpected and fluctuating demands upon the motive power. Electric railway work up to the present has demanded considerable of the motive power in the way of meeting large momentary overloads, running at different speed, line voltage, etc., and the direct current series motor has shown itself well equipped to meet these requirements. The induction motor is more adapted for operation under predetermined conditions, and its design does not lend itself to the same broad field of usefulness now covered by the direct current series motor.

In a service calling for frequent stopping where the demand upon the motors is largely acceleration work, the induction motor must dissipate considerably more energy for the same service performed than the direct current motor, and hence must be correspondingly heavier and more expensive. For constant speed running, the induction motor, however, must dissipate but little more energy than the d. c. motor, and from the nature of its design may dissipate that energy more rapidly.

This brings up a new class of railroad work just being considered, and that is mountain railroading, and long-distance cross-country roads for either high-speed passenger or freight work. The conditions governing both these classes of work are practically the same in that they demand a constant sustained output of the motive power, and it is in this class of work that the induction motor is being seriously considered.

Direct current motors fed from a system of rotary converters connected to a high-potential transmission distribution system are open to the objection that a trolley or third rail potential under 1000 volts must be used, necessitating the collection of very large currents and an undesirable frequency of converter stations, or prohibitive expense of third rail and feeder construction. The power consumed by a freight train of 2000 tons or more may reach 3000 H. P. on the grades encountered in steam railway mountain work, and the ability of the induction motor to collect this large amount of energy at a trolley potential of 3000 volts or more, gives it a distinctive advantage in first cost of installation and expense of operation compared to direct current distribution. High potential alternating trolley systems present certain difficulties in the way of insulation, but after several years experience with high potential transmission lines, these difficulties should be easily surmounted. Such systems also employ locomotives and not individual motor cars, so that the high potential apparatus is localized, and more space is provided to properly insulate all high-tension wiring.

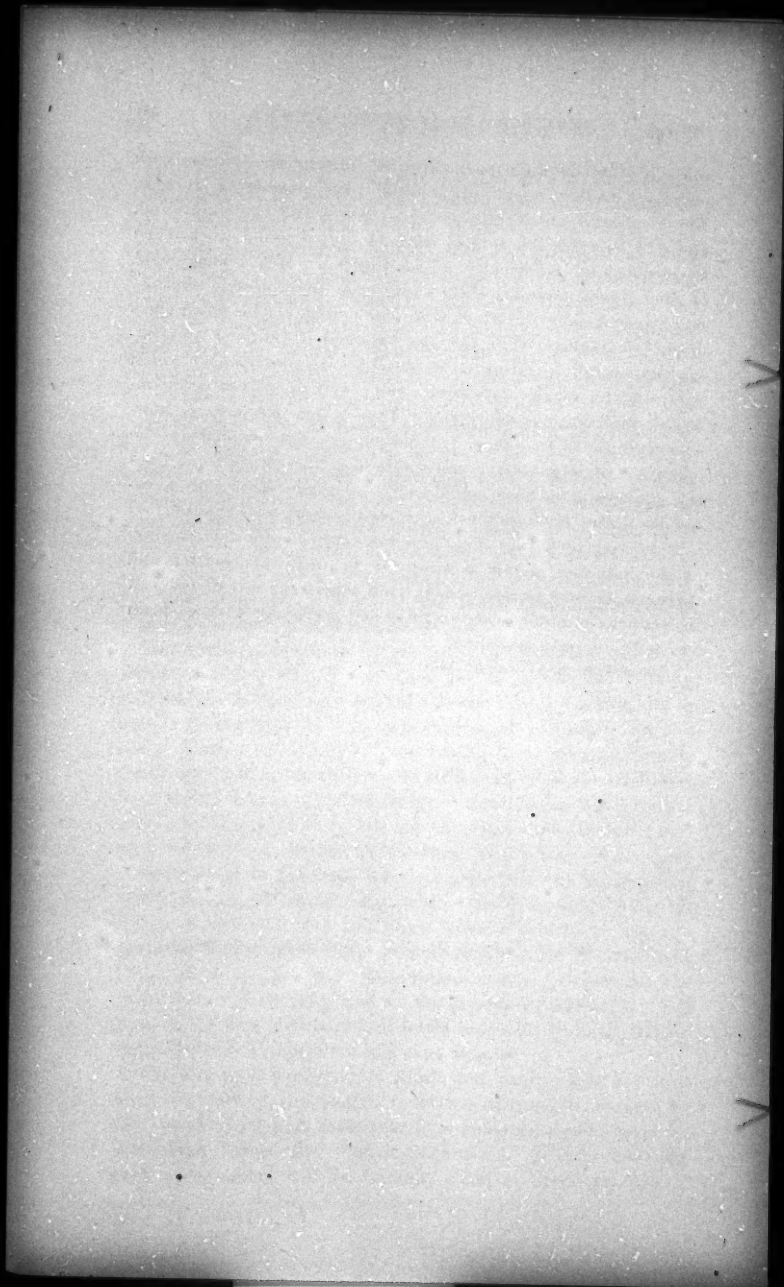
The operation of heavy freight trains, or high-speed passenger trains on trunk lines is the work of the future, and will be undertaken as soon as it is evident that a saving will result in operating expenses by the substitution of electricity for the steam locomotive. Trunk lines having local passenger traffic could very well equip their tracks with both high potential overhead trolley for the operation of heavy through trains and freight work, and also use a third rail construction to operate direct current 600-volt D. C. motors for the short haul work. Both these systems could be fed from the same generator and transmission lines, operating 25-cycle rotary converters to feed the third rail system at intervals, and step-down transformers to reduce the potential to the 3000 volts or more required for the overhead high-tension trolley line. This mixed system provides for the maintenance of a steady load on the generating station, while it permits the local and short haul traffic to benefit from the advantages of the D. C. motor for this class of work.

The electrical equipping of trunk line steam roads is a very large engineering proposition, involving such radical changes in the operation of such roads that its commercial success must be undoubted before the work is undertaken. It is possible that such a movement will be brought about by the equipping of

some of the new high-speed third rail interurban systems with overhead trolley operating at 3000 volts alternating current. These systems are rapidly being extended and interconnected, and will soon be able to take care of long distance work when the systems are sufficiently joined together. The management of such roads, owing to their experience with electric traction, may be reasonably supposed to be more open to the advantages of electric haulage, while the establishment of a line of generating stations, all operating at the standard frequency of 25 cycles, will offer the means of feeding such a system with a comparatively small cost for equipping. The various substations, however, and the d. c. copper distribution are not adapted to the operation of large heavy units, although the transmission lines and generating stations could well feed these trains with a reasonable outlay for high-tension overhead trolley construction.

It is along such lines that the writer looks for the introduction of the induction motor as a railway factor in this country, and there are several propositions in view where the introduction of the induction motor seems justified and preferable to the steam locomotive now in operation.

Schenectady, N. Y., July 31, 1901.



ELECTRIC RAILWAY APPARATUS.

BY ERNST J. BERG.

With the extended application of electricity to heavy railroad work within the last few years, a number of interesting features have been brought out, the most important being what system to adopt and what apparatus to use in each particular case.

The object of this paper is to discuss the characteristics of the various apparatus, and, to a certain extent, their limitations, which, indeed, have almost entirely the deciding influence on the choice of system. The discussion of storage batteries is purposely omitted since their characteristics are well known and have been written up very fully within the last few years.

Continuous Current Generators.—By far the greater number of these are of the direct connected type. Their frequency varies from 6 to 15 or 18 cycles, and in some cases as high as 25 cycles. This latter frequency is adopted when, in addition to commutator, the generator is supplied with collector rings intended to take off more or less of the power as alternating current, that is, when the machines are "double current generators." With the exception of more extended use of direct connected units and double current generators, which are able to supply alternating as well as direct current power, very little if any radical modification in design or characteristics has been made during the last few years, but the progress has rather consisted in a steady and gradual improvement of design, especially in regard to sparkless commutator and overload capacity. Although the standard machines are over-compounded, in actual operation as a

rule the direct current potential is kept constant at all loads, the over-compounding being used only to compensate for drop in speed with the load. When used as double current generator, the compounding on the direct current side is taken care of in the same way as when used as direct current machine, that is, by series winding, and the compounding for the alternating current load made by phase control, that is, the load, which usually is rotary converters, is made to take leading or lagging currents which react on the machine and thereby raise or lower the voltage as the demand may be. In order to accomplish this satisfactorily, the double current generators should have fairly high armature reaction, which means not too close regulation. This high armature reaction, usually less than standard direct current practice, is not objectionable from the direct current generator point of view since the regulation of potential is taken care of by the series field. Nevertheless it has been customary to ask for a regulation as close as 6 per cent. on the alternating current side, the intention being not to attempt any phase control, but permit the voltage to drop slightly with the load. Under these conditions obviously the closer the regulation, the better. The limit is reached when, due to the necessarily low armature reaction and the many armature circuits in multiple, the cross current caused by slight inequality in pole shape or gap becomes excessive.

Alternating Current Generators.—These are in almost every case directly connected to the steam engine and operated at a frequency of 25 cycles per second. If, however, a considerable portion of the power must be used for lighting, a higher frequency may be used. It must, however, be borne in mind that satisfactory parallel operation depends largely upon the frequency, and that the tendency to hunt, and in general, the difficulties of operating any installation satisfactorily, increase as the frequency increases. Twenty-five-cycles has the disadvantage that it is too low for in-door and for efficient out-door incandescent lighting, and entirely too low for arc lighting, therefore it is hardly advisable to use it for any kind of lighting, but when such has to be done, it is accomplished by rotary converters or motor-generator sets or frequency converters. Twenty-five-cycles has, however, so many advantages for railway work that it must be recommended, at least in all cases where induction motor-direct current generator sets are not advisable. The generators are usually designed for a regulation of about six to ten per cent.

In view of the fact that usually a great many are operated in multiple in the same station, and therefore the load on individual feeders does not seriously affect one machine, it is preferable to go to rather high armature reaction since this limits the maximum flow of current and power in case of short-circuit, and suppresses large cross current when operated in multiple from generators of not too close speed control. The European practice is to design these generators with polar windings for securing satisfactory parallel operation, but this has not been found necessary in America, where strict demands have been made upon the steam engine builders, who thereby not only proportion their machines with great care, but pay particular attention to the fly-wheel and governor construction. These generators are always of the revolving field type, and usually installed in connection with independent fly-wheel, whereas the practice in Europe is to make the armature of such a great fly-wheel capacity as to combine the fly-wheel and armature in one structure. One reason for the universal adoption of the fly-wheel type in Europe is that in most cases 50 cycles are used. With 50 or 60 cycles, and particularly with high-voltage machines, the diameter of the revolving field is, as a rule, enough to render it available as a fly-wheel, whereas with 25 cycles with relatively low peripheral speed, the cost of an unnecessarily heavy revolving field is often greater than that of an additional fly-wheel. Almost without exception they are designed for three-phase current and voltages ranging between 2000 and 13,000, depending upon the distance of transmission, etc. When used for voltages less than 6000, they have as a rule three slots per pole and phase, and for higher voltages two slots per pole and phase. The poles and the slots are shaped so as to give as nearly a sine wave as can be obtained by using machine-wound coils. (The use of machine-wound coils and entirely open slots is contrary to the European practice, at least until very recently, the practice being to use hand-wound coils in almost entirely closed slots).

Although smaller alternating current generators are made with automatic compounding, in no case is such compounding used with large direct-connected machines for railway work, but the control is done by hand, and the fields have only one winding.

Inverted Converters.—These are in their constants essentially direct current machines operating at 25 cycles, and are used to transform from direct current as obtained from the station

bus bars to alternating current, which after being transformed to higher potential, is transmitted to sub-stations a considerable distance from the main station. The use of inverted converters is decidedly more efficient than the use of boosters, and is being introduced considerably. Although an inverted converter and a straight converter, that is, a machine transforming from alternating to direct current, to all appearances are identical, it is not always advisable to use one or the other indiscriminately. An inverted converter should preferably have lower armature reaction than a straight converter, and consequently is, as a rule, a larger and more expensive machine. The object of the lower armature reaction is to obtain closer speed control and to prevent as much as possible the tendency of the inverted converter to run away, in case suddenly an alternating current load of considerable magnitude or of very low power factor is thrown on. But even with inverted converters of such design it is not advisable to omit speed limiting devices, which may consist of a circuit breaker in the direct current leads in connection with a centrifugal device, or the inverted converter is excited by a special exciter directly connected or belted thereto. Indeed such exciter or "a compensated exciter" is very essential for the frequency control. The plain exciter may be shunt or compound wound whereby it is easily seen that as the rotary begins to speed up, the exciter also speeds up and its voltage rises, causing more current to flow through the shunt fields, which has a tendency to prevent acceleration. The compensated exciter, which is also a direct driven exciter, changes its voltages not only with the speed, but with the phase relation of current, increasing the voltage with lagging current going from the converter and lowering it when leading current is taken, which obviously is just what is wanted for close speed control. The ratio between the alternating current voltage and the direct current voltage depends upon the system, characteristics of the machine, etc, and is discussed later in connection with converters proper. It suffices here to state that it is a fraction, or in other words, the alternating current voltage is always less than the direct current voltage. It is therefore obvious that the alternating current delivered from an inverted converter is always of too low a potential to be used directly, and step-up transformers have to be used. In its potential control an inverted converter has not the feature of a direct converter of compound-

ing for the load if required, but the voltage will drop with the load unless made up entirely of converters, which by taking leading or lagging current can react upon the inverted converter, but even with such load only a very low compounding can be obtained. Therefore, as a rule, the voltage of an inverted converter will drop with the load. In order to obtain constant potential at the receiving end of the system it is necessary that the converter proper should be compound wound and that reactances should be inserted in the leads so that the rise in voltage can be obtained across these reactances instead of at the inverted converter. Frequently inverted converters are operated in parallel with alternators on the alternating current side, and it is then as important to investigate the speed regulation of the prime mover driving the alternator as when contemplating running such alternators in multiple, since the inverted converter naturally runs at a uniform rate of rotation and therefore if the alternators to be run in parallel therewith are not run at a uniform rate of rotation, cross currents will be caused and serious difficulties might arise.

Rotary Converters.—Although converters of a higher frequency than 25 cycles occasionally are used, in most cases, and particularly when the plant is intended for railway work, 25 cycles are chosen and the discussion will therefore apply to them. Were it not that rotary converters some times cause trouble by hunting, there is hardly any doubt they would be used universally, even with the limitations in voltage control imposed by their use, instead of synchronous motor or induction motor direct current generator sets. The question of hunting, however, is so serious that frequently it is good policy to introduce the complication of running two or three machines instead of one, even at the lower efficiency, to ensure satisfactory service. Hunting is caused by many circumstances, one being that the rate of rotation of the prime mover is not uniform, another that converters are operated in the same network, but interlinked by lines of relatively high resistance, another that the converter has sluggish magnetic circuit so that it cannot quickly respond to variations in impressed voltage, still another that the impressed voltage on the converter, for some outside reason, tends to fluctuate suddenly. The remedy for the first case of hunting is obviously to get the rate of rotation of the prime mover more uniform, which often is very difficult, particularly if the ma-

chines are already installed. (With the stipulations imposed upon the engine builders, this case of hunting is not now so serious and does not exist when the generators are driven by turbines.) Another remedy which occasionally gives satisfactory results is to use one or more induction motors of considerable size on the same circuit, or even a small induction motor with large fly-wheel, the tendency of the induction motor being essentially to steady the frequency by its momentum. The other cause, that of considerable resistance losses between converters or generators and converters, has a tendency to set up hunting also, since with a slight fluctuation in current, due to various causes, the voltages fluctuate also. This fluctuation in impressed voltage will react in the rotary converter, and if the magnetic circuit is not very sensitive, causes a state of unstable equilibrium which leads to hunting. It is obvious that if the E. M. F. supplied to the armature varies suddenly, the flux also must vary at the same rate to ensure the same relative position of the armature and the field. If the magnetism lags behind, the armature must take a different position from what it would have otherwise and thereby a pulsation in speed is set up and the rotary "hunts." It is therefore evident that the magnetic circuit should be as responsive as possible, in other words, all causes delaying change of magnetism should be eliminated. As a consequence it is not best to use magnetic material of low ohmic resistance, such as steel, but a considerable part of the magnetic circuit is made of cast iron which has high ohmic resistance, and damping devices are inserted not in the path of the main flux, that is in the poles, but midway between the poles. This damping device is only effective when the rotary hunts, that is, when there is an appreciable armature reaction which sets up currents to the circuit formed by the bridge. The last cases of hunting can be explained and remedied in much the same way as in the previous case, and sometimes preclude the use of converters in places where the rate of rotation might be uniform and where the ohmic losses between generators and converters might be small, the disturbing element being a fluctuating load placed near to the converter and therefore inducing periodic pulsations in voltage on the converter circuit.

Summarizing the hunting situation, we find that although there are a number of causes for this trouble, the phenomenon is fairly well understood and no great difficulties need be ex-

pected in well planned 25-cycle systems. The other limitation of rotaries is the difficulty of obtaining wide range of voltage as compared with direct current generators, and providing for automatic compounding over a wide range.

Although it is possible to compound rotary converters to some extent by merely using a series field similar to that on direct current generators, the amount of compounding is very slight indeed and is obtained by leading or lagging currents taken by the converter and passing over the very low reactance of the converter armature proper. In order to compound to any considerable extent, it is necessary to have some reactance in the circuit between converter and generator, and to permit the converter to take wattless currents at almost all loads. The proportion of wattless current and reactance can be varied considerably, and still the same results obtained, so for instance, roughly speaking, 10 per cent. compounding can be obtained by 50 per cent. leading current and 20 per cent. of reactance; or by 20 per cent. leading current and 50 per cent. reactance, etc. The more reactance over a certain limit, the more liability of an unstable operation and the more wattless current, the poorer the power factor at light loads, and the greater the armature heating; indeed, with quarter-phase or six-phase converters the saving in armature copper is not great over that in three-phase converters, if too large a percentage of wattless current is used in phase control. A fair average is to insert about 15 per cent. reactance. With such reactance in a circuit of 6 per cent. resistance, it is possible to obtain constant potential at all loads with a power factor of 60 per cent. at $\frac{1}{4}$ load, 91.5 at $\frac{3}{4}$ load, 100 per cent. at full load, 99.5 at 50 per cent. overload, and 96.5 at double load, or even higher if the series field is so adjusted that the converter runs non-inductive at $\frac{3}{4}$ load, then a power factor of 73.5 at $\frac{1}{4}$ load, 97.5 at $\frac{3}{4}$ load, 100 per cent. at $\frac{3}{4}$ load, 99.5 at full load, 98 per cent. at 50 per cent. overload, and 96 per cent. at double load. Under these conditions the voltage not only is approximately constant over the whole range of loads, but is still within a fraction of 1 per cent. up to 50 per cent. overload.

With several rotary converters operated in the same station, it is advisable to use independent transformers, or at least independent secondaries for each transformer, since, if this is not the case, considerable cross-currents are likely to flow if the direct current brushes on each individual converter are not placed identically the same.

The transformers themselves should preferably be designed with the greatest amount of self-induction, since, as stated above, in almost every converter installation some reactance is advisable. Thus the essential difference between a transformer used for lighting and a transformer used for converter is that transformers for rotary converters have more self-induction and higher efficiency than lighting transformers, or at least that in the design of these transformers this condition has been looked for.

The great advantage of rotary converters over motor-generator sets is the higher efficiency, due to the small copper and iron losses, and the facts that only one machine is used instead of two or more, that the power factor can be 100 per cent. at all loads, that they can act as condensers, and therefore compensate for lagging currents introduced by other apparatus on the system, that, in case of a very heavy load, they can give almost unlimited power, and that even as such shunt machines the voltage does not materially change with the load, but that it will at the most vary a few per cent. between no load and full load, whereas the direct current machine probably will vary perhaps 10 per cent. or more under the same conditions.

The ratio between alternating and direct current E.M.F. of a converter or inverted converter depends upon the system used, upon the ratio of maximum to square root of mean square value of impressed E.M.F. (that is, the E.M.F. given by the generating apparatus), upon the load of the machine, upon the ohmic losses in the machine, upon the position of the direct current brushes on the commutator, upon the excitation, upon the ratio of pole arc to pole pitch, and upon the operating conditions, that is, whether the machine is used to convert alternating to direct current power, or vice versa. Sixty cycle converters, which usually have shorter pole arc and higher commutator losses than 25-cycle converters, have, as a rule, higher ratios, and when used as inverted converters, lower ratios than 25-cycle machines.

At no load, with an average wave shape such as given by standard generating apparatus, the average ratios are:

Percentage pole arc	67%	74%	80%
Three-phase and six-phase double delta:....	62	61	60.5
Six-phase, diam. and two-phase	73.5	71.5	71

With the average losses at brushes and armature winding, this will give the following ratios at full load of a 550-volt converter:

Percentage pole arc	67%	74%	80%
Three-phase and six-phase double delta.	63	62	61.5
Six-phase diam. and two-phase.....	73.5	72.5	72

INVERTED CONVERTER.

Percentage pole arc.....	67%	74%	80%
Three-phase and six-phase, double delta.....	61	0	59.5
Six phase, diam. and two-phase.	71.5	70.5	70

The values apply when the direct current brushes are placed on the exact neutral point. If the brushes for some reason or other are placed either leading or trailing, these ratios are increased, that is, the direct current voltage for a given impressed alternating current voltage is less. This variation may amount to several per cent., therefore moving the brushes makes it possible to lower the direct current voltage, and thereby change the ratio to some extent without changing the transformer connections. It is, however, impossible to increase the direct current voltage, no matter in what position the direct current brushes are placed.

Changing the excitation will also change the ratio. With reduced excitation, that is, with lagging current, the ratio may increase a couple of per cent., and with over-excitation it may drop a couple of per cent. depending upon the electrical constants of the machine.

Synchronous Motor Driven Direct Current Generators.—These have the advantage over the rotary converters that they can be run on circuits of high voltage directly, without the use of step-down transformers, that the direct current voltage is independent of fluctuations in voltage on the alternating current side, and dependent only upon the speed control, and that by a mere change of field excitation the direct current voltage can be varied over a very wide range. Their limitation, however, is their tendency to hunt, which is quite as marked as with rotary converters. In other words, the limitations inherent to rotary converters exist also with synchronous motors and even to a greater extent, at least with synchronous motors wound for high voltages with relatively few slots, with which type it is decidedly more difficult to apply anti-hunting devices than with rotary converters, which, by their more distributed winding and large number of small slots, are less likely to have excessive eddy losses, in the anti-hunting devices. It is, therefore, questionable whether it is advisable to substitute such sets for converters under any con-

ditions, the more so as frequently the cost of a synchronous motor wound for very high voltage is not much less than the step-down transformers and a low voltage motor.

Induction Motor Driven Direct Current Generators.—This combination has decided advantages over the first mentioned types by its stability, and may therefore find considerable field of application in systems of unstable frequency and fluctuating voltage, or installations which already have a number of synchronous apparatus. As stated regarding rotary converters, it is some times possible to obtain good results with hunting converters by installing induction motors of considerable inertia on the same circuit, and such a set naturally lends itself very well for this purpose. At moderate voltages, up to say, 2000 to 3000, induction motors can be built with good constants at a reasonable cost, and do not, therefore, involve the use of step-down transformers. At higher voltages, however, and particularly up around 10,000 volts, it is found that the use of step-down transformers not only introduces much better constants but frequently makes a cheaper installation. Under these conditions it is decidedly questionable whether it does not pay to install more line copper, remedy the speed control of the generators, or, in general, remove the causes prohibiting the use of rotary converters, since the cost of such motor generator sets is much higher, and the contents much lower, than when converters are used.

Direct Current Railway Motors.—The characteristics of this type of motor are so well known that it is not worth while to discuss them further than to say that in general the tendency seems to have been during the last few years to design the motors for a given train weight and maximum speed, disregarding the number of stops, provided the car is accelerated and retarded at a comfortable rate, which involves, of course, the schedule speed changing with the number of stops.

To accomplish this, the motors are so designed and particularly the ventilating conditions are such that the temperature of the fields will not rise more than a safe number of degrees if subjected to the accelerating current at the rate of say, ten times per mile, and the armature has such a low core loss that it can run for a considerable time at the maximum speed. Such condition is made possible with the modern mechanical design which readily conducts the heat from the inside to the outside, and thereby obviates great differences in temperature. The main

difference in electrical design is that much more precaution has to be taken to have low self-induction in commutation. This is necessary since, as stated above, the field winding has to stand the full current of acceleration for a much longer time than formerly was the practice, and therefore a less number of turns and a weaker field in general is used in modern motors, this condition causing sparking unless the armature reaction is reduced and the number of commutator segments increased. We therefore find now as a rule a higher flux and a greater number of commutator segments than in older types of motors.

Alternating Current Railway Motors.—A very superficial study will show that whenever this type of motor has been adopted the reason lies, not with the motors themselves, but in the fact that a lesser amount of feeder copper and possibly fewer attendants are required with an alternating current railway system than with a direct current system involving rotary converters. It is, however, only in cases of relatively long runs with few stops, or in mountainous roads where power can be returned by induction motors, that economy can be shown with this system as compared with the direct current system. It is very doubtful whether in many cases where alternating motors have been installed, direct current motors would not have been better engineering.

The alternating current railway motors are of the polyphase induction type and therefore their characteristics are essentially those of direct current shunt motors, that is, they run efficiently only at one speed, whereas the direct current series motor will operate at high efficiency over a considerable range of speed. It is therefore obvious that in railway service where the speed for many reasons has to vary during the run and where cars are stopped and started at rather short intervals, the actual power taken by the induction motor will be greater than that taken by the direct current motor. Since, furthermore, any induction motor must take a certain amount of wattless current, the apparent power input of the motor must be greater than with direct current. With the same mechanical clearance in the two types of motors, the amount of wattless current taken by the induction motor would be quite prohibitive, therefore these must be made with decidedly smaller air-gap than direct current motors, which necessitates more careful adjustment, and involves more repair work. The wattless current is also dependent upon the

voltage at which the motors are operated, and increases as the voltage increases. With the known methods of insulation and with the limited space available for railway motors, it seems that it is almost out of the question to consider a design at higher potential than 3,000 volts. Even with the smallest safe air-gap this will give a power factor of at the most 85 per cent. or 88 per cent. at full load under the best conditions, which with an efficiency of say 86 per cent. including gear loss, gives an apparent efficiency of at the most 77 per cent.; in other words, the K.V.A. input of the motor would be about 30 per cent. greater than that corresponding to the work done. Whereas with the direct current motor the power input would probably not be more than 12 per cent. or 15 per cent. greater than that corresponding to the work done. Therefore, and in view of the laws governing the design of such induction motors, it is to be expected that the copper losses in an alternating current motor will be decidedly greater than in a direct current motor. The core loss in the field of the induction motor is also greater than the core loss in the armature of the direct current motor at maximum speed, so that this gives another source of increased heating of the motor. This increased heating is decidedly objectionable, as it involves the use of a much larger machine than the direct current motor, which increases the cost and weight of the equipment. To illustrate this somewhat more concisely, consider the losses occurring in a couple of motors of direct and alternating current type while accelerating from standstill up to full speed. The core loss and eddy losses in the direct current motor are zero at standstill, and increase to a certain maximum at full speed. In the alternating current motor at standstill even under favorable conditions, the core loss in the field is the same as the maximum core loss in the armature of the direct current machine, and the core loss in the armature at standstill about the same as in the field. At full speed the core loss in the field still remains the same, but the core loss in the armature is zero and therefore, roughly speaking, the core loss of the direct current motor is in the neighborhood of half of the core loss at maximum speed, while accelerating, and is one and a half times as much in the alternating current motor. In other words, during acceleration the alternating current motors have three times as much core loss as the direct current. Adding to this loss the greater copper loss due to the larger power input of the motor, we find from

actual calculations that the alternating current motors of good design will have in the neighborhood of four times as much loss as the direct current motors when operating over relatively short lines, as would be the case in rapid transit systems. To dissipate four times as much energy means that the volume of the motor has to be very much greater, and its heating facilities decidedly better. This does not mean that the actual heating will be as much

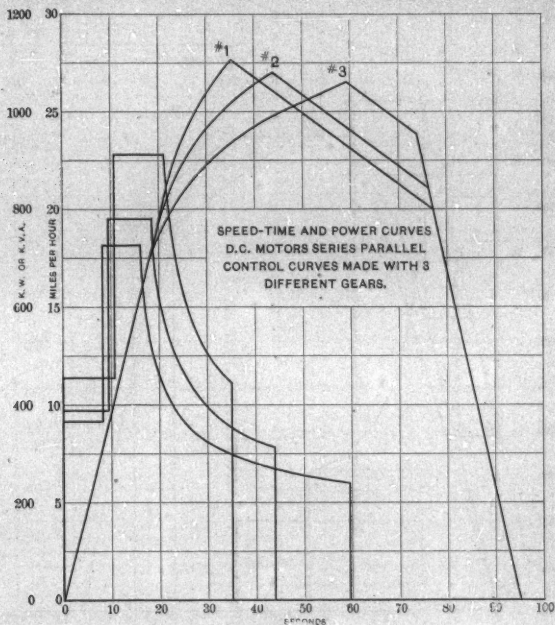


FIG. 1.

more, since at least in long distance runs, the time of accelerating is short compared with the total time of the run, nevertheless the loss will be decidedly more and consequently it would seem as if the actual cost of the induction motor equipment per car would be from 50 per cent. to double that of direct equipments, depending upon the service. Since the cost of the motor equipment is a very large factor in the installation of a plant, and

since the direct current equipment is so standardized and brought down to the least possible cost here in the United States, this is

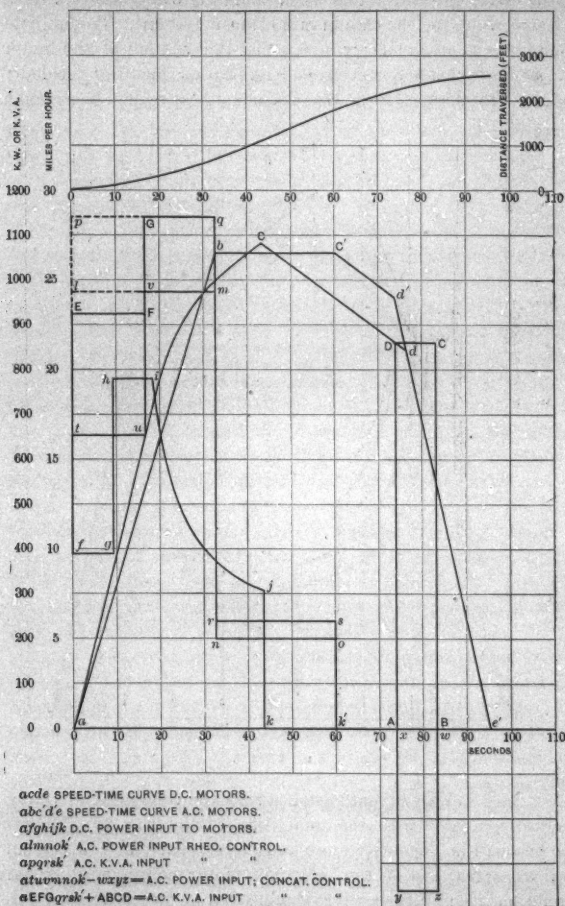


FIG. 2.

probably one of the main reasons why upon careful examination it has been found not only a saving of power, but great economy

in the first cost to install direct current rotary converters instead of alternating current systems. In places, however, where the direct current railway system is not so fully developed, the difference in cost between the two systems might

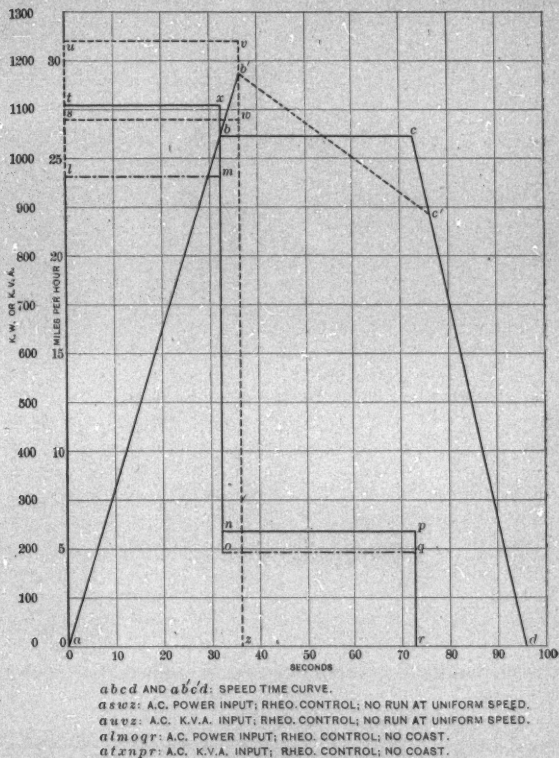


FIG. 8.

not be so much, and that accounts for some European concerns installing alternating current motors.

To illustrate more fully the characteristics of the two types of motors, the following instance is considered, although it neces-

sarily introduces some questions slightly outside of the scope of the paper.

A double track road with 27 stations is supplied power from a station located a distance from the tracks. Eight trains are running in each direction, which cover the entire distance in 53 minutes.

Weight of loaded train, including locomotive = 180 tons (2700 lbs.)

Weight on driving wheels, = 50 tons.

Thus maximum drawbar pull at 2% of weight = 25000 lbs.

Which corresponds to a maximum acceleration of two feet per second, per second.

Distance of run is 2560 feet.

Schedule speed, 15 miles per hour.

Maximum speed, 27 miles per hour.

Total distance is covered in 95.5 seconds, 20 seconds allowed for stops at each station.

No appreciable grades exist and effect of curves is negligible.

The three systems considered are:

A. The standard direct current railway system with series parallel control of the motors.

B. Three-phase induction motor system with rheostatic control.

C. Three-phase induction motor system with concatenated control in accelerating as well as braking.

Obviously when running at uniform and maximum speed one system offers no advantage over any other in energy consumption, assuming same efficiency of the motors (which is very nearly the case) while the volt-amperes taken by the motors are about 20 per cent. greater with the alternating current system (running at relatively light load).

While braking, the use of either of the first mentioned systems is immaterial, since no return of power can take place, but the third, that with concatenated control, offers some advantage in returning power which, however, is practically offset by the large current taken, and the complication of control and design of motor.

While accelerating, however, marked differences exist in the three systems, therefore the choice of one or the other is largely dependent upon the relative time of accelerating, running at uniform speed, and braking. Since, furthermore, the power required with any particular system depends upon the method of accomplishing the run, a number of schedules have been worked out.

So, for instance, in Fig. 1 are given three runs with direct current motors. Of these, Nos. 1 and 3 require more power than No. 2, therefore No. 2 run is referred to as the direct current motor run in the discussion following.

In Fig. 2 are given what is considered the best alternating current runs. One curve shows the conditions with rheostatic control, and the other with concatenated control in accelerating as well as braking. These two curves will be referred to as the alternating current runs in the discussion following.

In Fig. 3 are given two runs with rheostatic control, both of which take more power than the corresponding run in Fig. 2, and are given merely to show that with widely different methods of running, the power does not vary more than 5 per cent.

In Fig. 4 are given two different runs in which concatenated control is used. These seem not so favorable as those in Fig. 2, therefore they are not referred to later except in the general table given below. The chief object of including them is to show the merits of coasting with concatenated motors. As should be expected, if the motors are connected in concatenation, when accelerating only, it is advisable to go up to as high speed as possible, and then coast without running at constant speed, whereas if power is returned by concatenation it is advisable to maintain the maximum speed until time of braking.

So, for instance, the least average power taken per run is found if the cars are not permitted to coast, but accelerated and retarded in concatenation, which power is only 15 per cent. more than the least direct current power. The apparent power is, however, 2.4 times as great. In view of this very large apparent power this method is not the most favorable, but that given in Fig. 2 is preferable.

The important results of the various runs are shown in the table given below, which undoubtedly is more comprehensive than the diagrams for a superficial investigation.

Columns A, B and C are most important, and show the conditions of the best runs. Upon the constants given there and the corresponding curves the rest of the investigation is based.

Columns D and E show two direct current runs at different gear ratios.

Columns F and G show two runs with rheostatic control only.

Columns H, I and J show three runs with concatenated control in accelerating only.

Columns K and L show two runs with concatenated control in braking as well as in accelerating.

In going over the matter in more detail are considered the direct current run as shown in heavy lines in Fig. 1, and in Column A, and the alternating current runs with rheostatic and concatenated control as shown in Fig. 2, and Columns B and C.

	A	B	C	D	E	F	G	H	I	J	K	L
	D. C. Series Parallel. 33 Seconds Coast.	A. C. Rheostat. 14 Seconds Coast.	A. C. Concat. 14 Seconds Coast.	D. C. Motors 43.5 Seconds Coast.	D. C. Motors 14.5 Seconds Coast.	A. C. Rheostat. 40 Seconds Coast.	A. C. Rheostat. No Coast.	A. C.—Concat. only when Accel. 40 Seconds Coast.	A. C.—Concat. only when Accel. 14 Seconds Coast.	A. C.—Concat. no Coast.	A. C. Concat. Brake and Accel. 40 Sec- onds Coast.	A. C. Concat. Brake and Accel. No Coast.
k. w. Seconds Accelerating.	21800	31700	25100	22700	23000	30100	31100	30000	20115	20042	00060	22222
k. w. Seconds Uniform Speed.		5400	5400				7800		5075	7092		24000
k. w. Seconds Braking.		2130	2130						30800	30065	20800	21000
Total k. w. Seconds	21800	37000	27770	22700	23000	30100	38900	30000	30800	30065	20800	24000
Average k. w. per Run	190	322	237	197	200	340	338	268	265	265	244	218
k. v. A. Seconds Accelerating.	21800	37000	33600	22700	23000	44900	35800	40000	33600	38100	40000	38100
k. v. A. Seconds Uniform Speed.		6600	6600				9500		6600	9500		9500
k. v. A. Seconds Braking.		7730	7730						40850	41600	5400	16600
Total k. v. A. Seconds	21800	43000	47990	22700	23000	44900	45300	40000	40850	41600	45400	38400
Average k. v. A. per Run	190	370	416	197	200	390	394	348	350	362	394	454
Maximum k. w. per Run	780	977	977	912	725	1080	665	1080	977	665	1080	965
Maximum k. v. A. per Run	780	1140	1140	912	725	1240	1110	1240	1140	1110	1240	1110
Watt Hours per Ton-mile.	70	120	83	73	74	126	125	99	98	98	91	81
k. v. A. Hours per Ton-mile.	70	138	154	73	74	145	146	120	120.5	134	146	168
Ratio Average a-c k. w.		1.72	1.26	1.80			1.79	1.41	1.40	1.40	1.37	1.16
Ratio Average d-c k. w.												
Ratio Average a-c k. v. A.		1.97	2.20	2.07			2.09	1.85	1.85	1.92	2.09	2.40
Ratio Average d-c k. v. A.												
Average P. F.	1	87	58	1	1	87	86	77	75.5	73	62	48

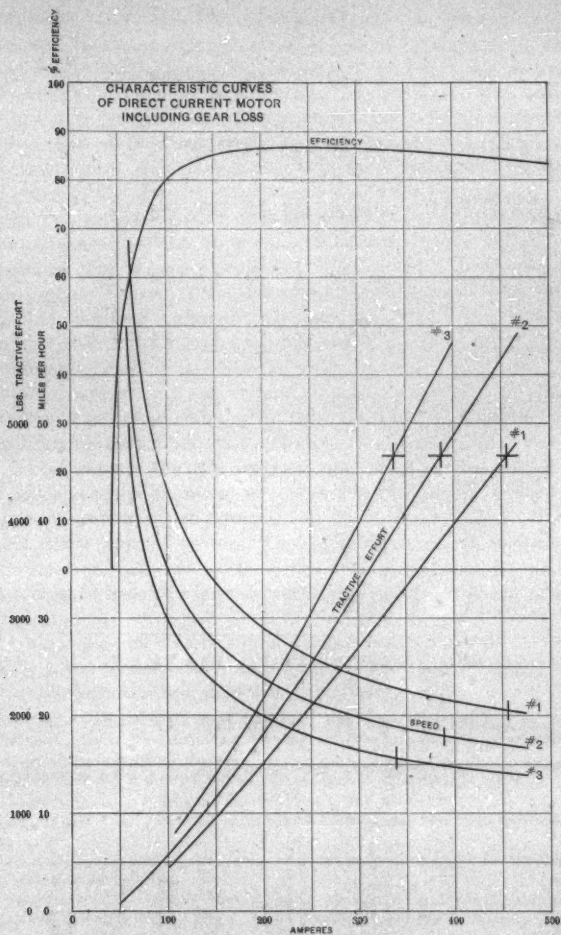


FIG. 5.

The characteristic curves of the motors are shown in Figs. 5, 6 and 7. Fig. 5 gives the direct current motor curves, Fig. 6 the alternating current motor curves, and Fig. 7 curves of the same motors in concatenation. No special curves are given for this latter motor when used as generator to return power, since it is essentially the same as when used as motor.

To sum up the results, it is found from the various methods of running trains, first, that under apparently the most favorable as well as average conditions, the most economical alternating current system will take 26 per cent. more power and 2.2 times as

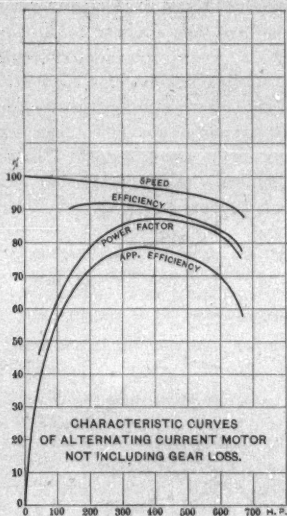


Fig. 6.

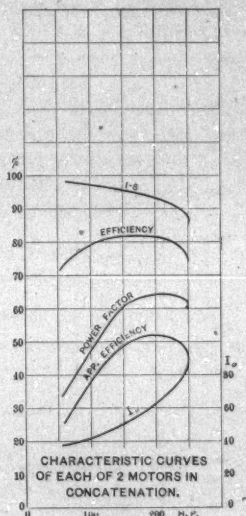


Fig. 7.

many volt-amperes as the direct current system. Second, that the concatenated control takes 26 per cent. less power but only 10 per cent. more apparent power than the alternating current system with rheostatic control. It must, however, be borne in mind that these values refer to power input at the motors, not the relations at the sub-stations and power-house, as will be seen later.

Power is supplied to four sub-stations located respectively 16,600 feet, 17,400 feet, 22,800 feet, and 35,000 feet from the generating station. The transmission potential is 11,500 volts.

Capacity of Power House, Electrical Machinery, Lines, etc.

—Since the supply of power is located at some distance from the receiving circuit, high potential three-phase generators are proposed in all three cases.

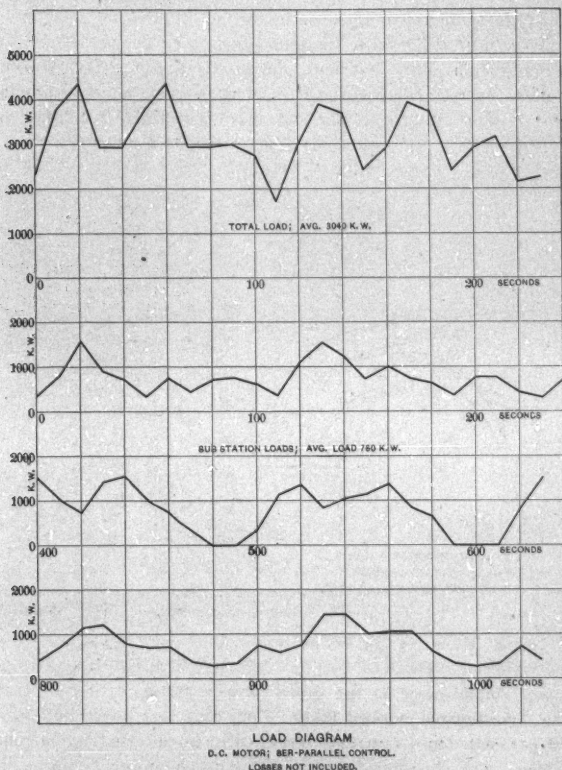


FIG. 8.

A. Direct current motors with series parallel control.

Installation.—The road bed has double tracks of 85-lb. rails and the combined cross sections of feeders and trolleys for two tracks is 1 sq. in. of copper. In the calculations all tracks and

feeders are assumed interconnected, and the feeder copper strung all around the track.

The resistance of steel rails is assumed as 12 times that of the corresponding copper, and that of bonds as 50 per cent. of rails. This gives the ohmic resistance of four rails in multiple between two sub-stations (average 17,100 ft.) as .09 ohms and the corresponding resistance of copper as .159 ohms, or a total resistance of .25 ohms.

Each sub-station has three 650 k. w. converters (one as spare) and ten 240 k. w. transformers. The high potential lines consist of two cables No. 0 B. & S. (one of which is spare) for each of the two distant stations and two cables No. 3 B. & S. for the two nearer stations.

Distance between sub-stations = 17,100 feet.

The transformers have two per cent. *I. R.* loss and one per cent. core loss. The converter has 94 per cent. efficiency over considerable range of loads. The generating station has four 1,600 k. w. generators (one as spare) and engines.

Referring to Fig. 8 we find that neglecting losses,

	Killowatts.
Average load in k. w. on one sub-station is	760
Maximum load on one sub-station is.	1600
Average load on the generating station is.	3040
Maximum load on the generating station is.	4400

This brings the average actual load on a rotary converter to 832 k. w.

Maximum load on rotary converter.....	1910
Average load on generating station.....	3650
Maximum load on generating station.....	5650

The converters run at	64% load at average load,
" "	146% load at maximum load.
The generators run at	76% load at average load,
" "	118% load at maximum load.

B. Alternating Current Motors with Rheostatic Control.—

The motors are supplied power from four sub-stations at an average potential of 3,000 volts over two sets of three-trolley wires, No. 00 B. & S. (interconnected). Each sub-station has four 700 k. w. transformers (one to spare). The high potential lines are two sets of No. 00 B. & S. and No. 2 B. & S. respectively for the longer and shorter distances.

The generating station has five 1,800 k. w. three-phase 11,500 volt generators and five 1,600 k. w. steam engines.

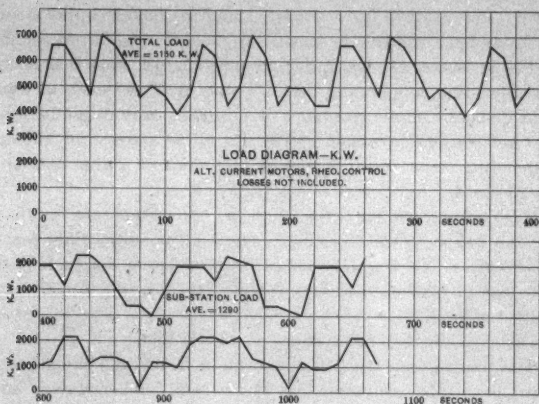


FIG. 9

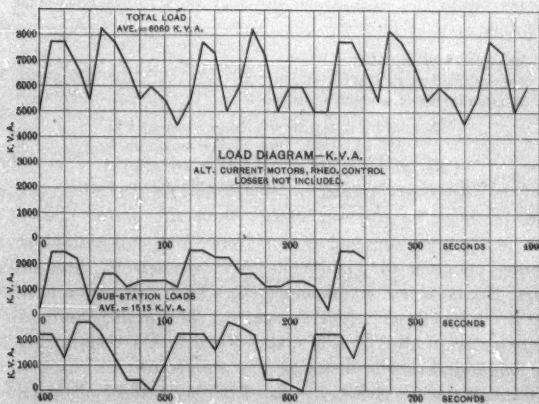


FIG. 10.

From the load diagrams, Figs. 9 and 10, is found that neglecting losses,

	Kilowatts.
Average power on sub-station is	1290
Average K. V. A. "	1513
Maximum power "	2300
Maximum K. V. A. "	2300
Average power generating station is	5150
Average K. V. A. " "	6080
Maximum power " "	7100
Maximum K. V. A. " "	8300
This gives an average K. W. output of power station	5600
" " K. V. A. " " "	6500
" " maximum K. W. " " "	7780
" " K. V. A. " " "	8880

The generators will run at 90% load at average load,
 " " 123% load at maximum load.

The engines will run at 92% load at average load,
 " " 126% load at maximum load.

C. *Alternating Current Motors, Concatenated Control.*—The secondary net work is laid out as in previous case, but the high potential lines are duplicate sets of No. 000 B. & S. and two No. 000 B. & S. cables in multiple for the shorter and longer distances respectively.

Each of the four sub-stations has four 800 K. W. transformers. The power station has five 2,000 K. W. generators and five 1,400 K. W. engines.

From the load diagram, Figs. 11 and 12, is found that neglecting all losses,

	Kilowatts.
Average power on sub-station is	948
" K. V. A. "	1660
Maximum power "	2000
" K. V. A. "	3500
Average power on generating station is	3800
" K. V. A. " "	6850
Maximum power " "	6000
" K. V. A. " "	10000
This gives an average K. W. output of power station	4170
" " K. V. A. " " "	6850
" " a maximum K. W. " " "	6000
" " K. V. A. " " "	10000

The generators will run at 86% load at average load,
 " " 125% load at maximum load.

The engines will run at 75% load at average load,
 " " 107% load at maximum load.

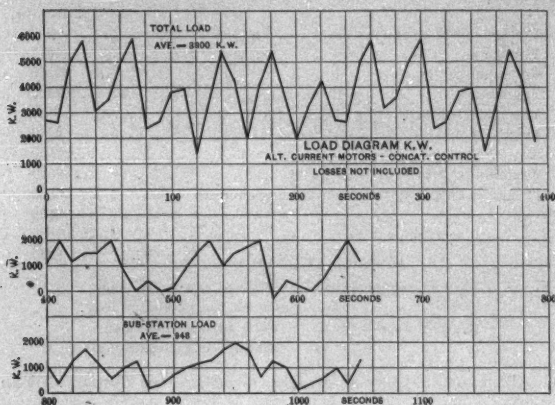


FIG 11.

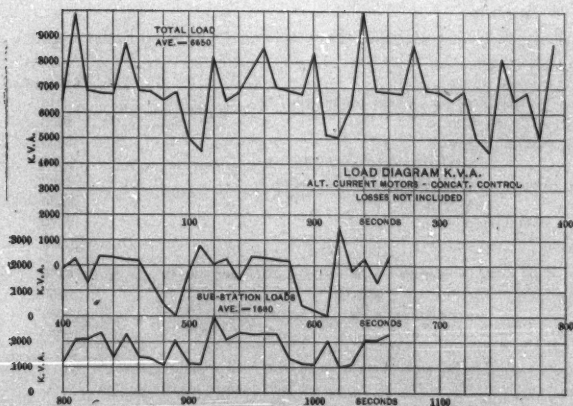


FIG. 12.

The selling prices of the various items referred to are assumed as follows:

Complete steam equipment, including installation.	\$75.00 K.W.
High potential generators, switchboards and instruments.....	26.00 "
Rotary converter sub-stations and apparatus.....	40.00 "
Transformers (700 K. W.).....	4.50 "
Direct current electric locomotive complete.....	\$15,000.00
Alternating current electric locomotive complete.	19,000.00
Passenger coaches (70 seats).....	4,500.00
High potential cables (10,000-v.) No. 000 B & S. . .	1,080.00 per M. ft.
" " " " " " 00 " ..	930.00 "
" " " " " " 0 " ..	840.00 "
" " " " " " 1 " ..	710.00 "
" " " " " " 2 " ..	650.00 "
" " " " " " 3 " ..	600.00 "
Copper	186 per lb.
Direct current trolley construction.....	900.00 per mile.
Alternating current trolley construction.....	1,200.00 "
85-lb. rails, per ton	26.00
Track construction	500.00 per mile.

EXPENSES OF INSTALLATION AND AMOUNT POWER REQUIRED.

- A. Continuous current motors with series parallel control.
 B. Alternating " " " rheostatic current.
 C. " " " " concatenated control.

	A	B	C
Power house steam equipment.....	\$490,000	\$800,000	\$525,000
" electrical "	166,000	234,000	260,000
	646,000	831,000	785,000
Rotary converter station	812,000		
Transformers.....		50,500	57,500
	812,000	50,500	57,500
17 locomotives, complete.....	225,000	323,000	322,000
68 passengers coaches	806,000	806,000	806,000
	531,000	628,000	628,000
Cables, duplicate.....	157,000	172,000	386,000
Trolley and feeder copper.....	49,000	81,000	81,000
	206,000	203,000	397,000
Track, material and construction....	109,000	109,000	109,000
Trolley construction.....	23,400	81,200	81,200
	132,400	140,200	140,200
Total cost.....	\$1,857,000	\$1,856,000	\$2,008,000

Average k. w. power required.....	3650	5600	4170
k. w. average loss.....	600	440	380
% loss.....	16.4	7.8	9.1
Percentage of d. c. power.....	100	153	114
Percentage cost of d. c. installation.	100	100	107

It is thus apparent in this particular instance, which is fairly representative for heavy urban work, that the direct current system offers decided advantages in economy if installed at the same price as the alternating current system, and that the same economy cannot be obtained with alternating current, no matter at what cost, furthermore, that the alternating current system with concatenated control is preferable to that with rheostatic control. It must, however, be borne in mind that for an actual installation, practical conditions might warrant different amount of machinery and different units, and that allowances must be made for sharp turns, grades, etc., and that the prices given are somewhat arbitrary. The three systems are, however, placed on as nearly as possible the same footing, so that the comparison should be fair, even if the actual cost of the installation is considerably different.

To conclude, it might be stated that due to the favorable characteristics of the direct current railway motor and the rotary converters, compared with the alternative current motor for this class of work, very few propositions warrant the use of the alternating current throughout. Indeed there is no question that the stand taken by the American engineers in this matter in recommending rotary converter systems almost exclusively, is correct and warranted by considerations of economy and first cost, no matter what the adverse criticisms have been of late. There is undoubtedly a field for alternating current motors, but it is strictly limited to long distance schemes with very few stops, or to mountain roads.

[ADVANCE COPY SUBJECT TO REVISION.]

AN IMPROVED APPARATUS FOR ARC-LIGHT PHOTOMETRY.

BY CHARLES P. MATTHEWS.

The usual process in arc-light photometry involves the determination of the distribution curve of luminous intensity in a vertical plane through the axis of the carbons, and the subsequent integration of a derived curve in rectangular co-ordinates (the Rousseau diagram).¹ The ordinate of this latter curve is the measured intensity, and the increment of the abscissa is proportional to the area of the elementary zone which such intensity illuminates of an imaginary sphere about the source. The mean ordinate of this derived curve is the value sought. Under the most favorable conditions this task is a tedious one, several hours being usually required for its completion.

Methods designed to shorten this process, through the production upon the photometer screen of an illumination proportional to either the mean spherical or mean hemispherical intensity of the source are not new. Of these integrating methods, the writer is aware of two due to Blondel,² and one due to Houston and Kennelly.³

Unfortunately, two of these methods are adapted only to the photometry of the open arc, while the third, although worked

1. See Appendix.

2. The Lumenmètre. *L'Éclairage Électrique*, March, April, May, 1895.
The Photomesomètre. *L'Éclairage Électrique*.

3. *Electrical World*, xxvii: 509. 1896.

out in a masterly manner by Blondel, requires a somewhat elaborate preliminary calibration. It is the writer's purpose to describe here an equipment which he has designed for the Photometric Laboratory of Purdue University, where it is now in satisfactory operation. This piece of apparatus, while embodying certain features of Blondel's apparatus, combines simplicity of operation with adaptability to either the open or enclosed arcs.

THEORY OF THE METHOD.

The mean spherical intensity and the mean hemispherical intensity of a source whose photometric surface is one of a revolution are given by the expressions:

$$I_{ms} = \frac{1}{2} \int_0^\pi I_\theta \sin \theta \, d\theta$$

$$I_{mhs} = \int_0^{\pi/2} I_\theta \sin \theta \, d\theta$$

Where I_θ is the intensity at an inclination of θ to the vertical. If the intensity I_θ be taken at n equal intervals through 180° , or n' equal intervals through 90° in a vertical plane, we may write

$$I_{ms} = \frac{\pi}{2n} \sum_0^\pi I_\theta \sin \theta$$

as the mean spherical intensity and

$$I_{mhs} = \frac{\pi}{2n'} \sum_0^{\pi/2} I_\theta \sin \theta$$

as the mean hemispherical intensity—expressions which are quite correct if n and n' be sufficiently large.

For example, let us consider the hypothetical distribution of intensity shown in Fig. 1, namely, a circle tangent to a vertical line. Here I is a known function of θ and we have

$$I_{ms} = \frac{1}{2} \int_0^\pi I_0 \sin^3 \theta \, d\theta$$

$$= 78.5$$

if I_0 be taken as 100.

*See Appendix.

Taking now $\Delta \theta = 15^\circ$ or $n = 12$, we have

TABLE I.

θ	$100 \sin^2 \theta$
0	0.
15	6.7
30	25.
45	50.
60	75.
75	98.8
90	100.
105	98.8
120	75.
135	50.
160	25.
175	6.7
	600.

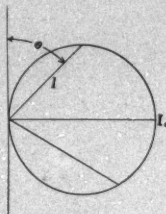


FIG. 1.

Whence

$$\sum_0^\pi 100 \sin^2 \theta = 600 \text{ and } I_{\text{ms}} = \frac{\pi}{2 \times 12} \times 600 = 78.5$$

It thus appears that with $n = 12$, the approximate formula yields a result amply correct.

To produce on the photometer screen an illumination proportional to the mean spherical intensity of the source, it is necessary, as the formula shows, (1) to direct towards the photometer the beams of light which the eye of an observer would receive if he were to view the source at angular intervals of 15 degrees in a vertical plane, and (2) to reduce the intensity of the light in these directions in the ratio of the sine of the angle between the direction of view and the vertical. The method of accomplishing this is described below.

DESCRIPTION OF METHOD.

A ring of 24 large trapezoidal mirrors, m, m , surrounds the arc. This system of mirrors constitutes a truncated, 24-sided pyramid. The inclination of the mirrors to the axis a of the system is such that the eye, placed at the photometer p , sees 24 images of the lamp L , of which L' is the horizontal one, precisely as if the mirrors being absent, one were to travel in a circle about the arc in the plane $00'$ stopping at 15° intervals. Figs. 3 and 4 show the aspect of this series of images from a point

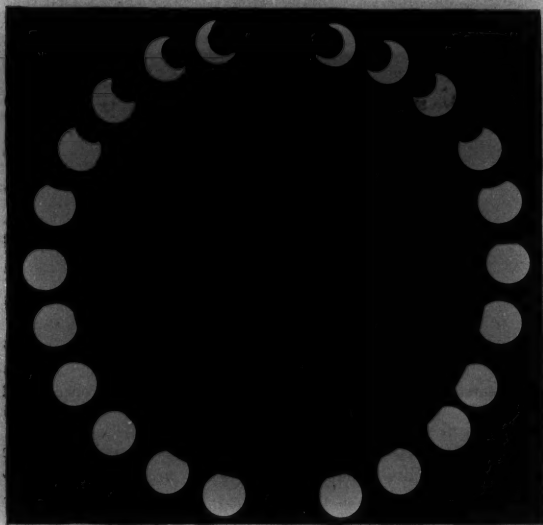


FIG. 3.—Arrangement for the Determination of the Mean Spherical Intensity.
[The slight amount of displacement in Figs. 3 and 4 is due to the fact that the camera could not be placed in the optical center of the system.]

near the photometer. The first figure shows the entire set of images as used in the determination of the mean spherical intensity, and the second figure the lower images only for the determination of the mean hemispherical intensity, as in the case of lamps with shades. As actually used, the top and bottom mirrors were left out, not because there may not be light in these

directions, but because these intensities, when multiplied by $\sin 0^\circ$, do not contribute to the mean spherical intensity. Direct light from the arc is intercepted by a black screen *s*.

This system of mirrors serves then to direct the light to the photometer screen in the chosen directions. The second condition is that the intensity of each beam of light shall be reduced in the ratio of the sine of the vertical angle. I have done this by a polygonal glass disk *D*, composed of as many sectors as there are mirrors. These sectors are smoked until they give the desired absorption. In order that the film of smoke may be permanent, the ring of smoked sectors is covered by two plates



FIG. 4.—Arrangement for the Determination of the Mean Hemispherical Intensity.

of plane glass. These plates cover but do not touch the smoked surfaces. The three thicknesses of glass are firmly bound together, and the screen as a whole may be handled without fear of changing its absorption. The precaution must be taken to thoroughly clean its external surfaces before making measurements. An essential condition to the success of this method is that the photometer screen should receive light through any given sector from the image in the corresponding mirror and from no other. That this condition is fulfilled, can easily be determined. Thus, if all the mirrors be covered except the horizontal one, and all the sectors be covered except the sector just above the horizontal, that is, at 15° Δ , then if the patch of light produced by this arrangement of the apparatus falls not

upon the photometer screen, but upon the black surface in the vicinity of the photometer, the required condition is met. The sector disk is best put in place by replacing the photometer screen by a cardboard pierced by a small opening. The observer can then sight through this hole, and ascertain the adjustment of the disk with reference to the system of mirrors.

CONSTANTS OF MIRRORS AND GLASS.

The mirrors are of good quality, French plate glass. Their reflection coefficients were carefully determined for the incidence at which they are used. Some inequalities were found, as would be expected, although the maximum difference from the mean value of .815 is only ± 2.9 per cent. The following table gives the coefficients of the 24 mirrors.

TABLE II.
Value of Mirror Coefficients K_θ .

Mirror Number.	K_θ	Mirror Number.	K_θ
1	.796	13	.820
2	.830	14	.832
3	.803	15	.798
4	.814	16	.818
5	.791	17	.818
6	.812	18	.809
7	.812	19	.798
8	.803	20	.812
9	.832	21	.812
10	.803	22	.812
11	.839	23	.830
12	.834	24	.812

It will be seen that these coefficients occur in pairs. This would lead one to believe that two mirrors were cut from one piece of glass. An inspection of the edges of the mirrors showed that this was very probably the case. The values are so nearly equal that for purposes of arc-light photometry sufficient accuracy would be obtained by using the mean value of .815. However, in order that the apparatus might be used for the measurement of steady sources, I have made up for variations in K_θ in the smoking of the corresponding glass sectors. That is to say, if the coefficient of a particular mirror were high, the corresponding glass sector was smoked a little heavier than would otherwise be done. In all cases the formula

$$(K_g K_s) K_\theta = (K_0 K_g) \sin \theta \text{ was satisfied.}$$

Where K_g = transmission coefficient of glass

K_s = transmission coefficient of layer of smoke corresponding to angle θ .

K_θ = reflection coefficient of mirror at angle θ

K_0 = reflection coefficient of horizontal mirror.

Since K_g and K_s must, of necessity, be obtained together, we have as the required transmission coefficient for the θ sector

$$K_g K_s = \frac{K_0 K_g \sin \theta}{K_0}$$

This value was computed for each sector and the glass smoked accordingly. It will be seen from this that the intensities are cut down as a whole in the ratio $K_g K_s : 1$, and furthermore, separately in the ratio $\sin \theta : 1$.

The mirrors were paired and put in position according to the following table:

TABLE III.
Position of Mirrors.

Position.	Mirrors.	Mean Constant at 40°
0	6 and 7	.812
15A	27 " 24	.812
30A	9 " 14	.832
45A	15 " 10	.798
60A	11 " 12	.837
75A	1 " 5	.793
15B	20 " 21	.812
30B	16 " 17	.818
45B	2 " 23	.830
60B	10 " 18	.809
75B	3 " 8	.803

Constant of Mirror behind Photometer at 12½° = .901.

Some care and skill are necessary to produce a uniform coating of smoke of just the required density. I have found it convenient to use a sheet iron chamber, fitted with a suitable flue, and pierced near the top with a small opening for the introduction of the glass. This chamber must be placed near one end of the photometer bar in order that the absorption of the glass may be tested as frequently as may be necessary. The setting of the photometer being predetermined, each sector is smoked until it shows the required absorption. There is a tendency for the coating to form most heavily near the edges of the glass. This may

be overcome by providing a guard ring of glass of the same thickness as the piece to be smoked, the whole being mounted in a convenient holder. The best results will be obtained by holding the piece of glass vertically in the smoke chamber, occasionally reversing the piece. Turpentine is a good combustible, but it must be introduced into the receptacle at the base of the chamber in small quantities, otherwise the combustion will be so violent as to produce a flocculent deposit on the glass.

In testing the glasses it is best to use a small source of light, such as a narrow slit in front of a straight filament glow-lamp. Any inequalities in the coating of smoke can be detected by moving the glass about in front of this opening, care being taken that the same plane is maintained. It will be seen in Fig. 2 that the incidence of the light upon the glass is not quite normal. Care was taken to maintain this same incidence in the absorption tests.

At M_s is shown a mirror for directing the light from the temporary standard to the photometer. This mirror might have been omitted had not the limits of the photometer room already been taxed to the utmost. Still better, if the mirrors were from one large piece of glass, the direction of the photometer bar might be such that the same incidence would be had on M_s as upon the others. In this case, the correction for the mirror absorption would be eliminated.

The illumination upon the arc side of the photometer screen is, of course, very intense. It is necessary to reduce this illumination. For this purpose, I have used a rotating wheel w , provided with a large number of narrow radial slots. It is quite essential that the number of open slots should be large, as otherwise the illumination on the photometer screen will be seen to beat or pulsate when measurements are being made on the alternating arc. In order to avoid the error found by Ferry¹ I have determined the constant of this wheel by direct experiment on the arc itself, and not by calculation. The mean of several determinations gives

$$\text{Transmission constant sector wheel} = K_w = .090$$

The number of slots in this wheel is 48, which gives a frequency amply great at the normal speed of the motor used for driving the wheel.

1. *Physical Review*, vol. i, p. 338.

A possible source of error is the diffusion of the smoked glass disk. That is to say, since the disk receives a certain flux of light dependent upon the solid angle which it subtends from each image as a center and upon the intensity of such image, it becomes, to some extent, a secondary source. The direct measurement of this is a matter of some difficulty. To determine if the correction for this diffusion were of importance, I proceeded as follows: The longitudinal screen ss' was removed, the mirrors to the left of the vertical were covered, and likewise the right half of the sectorized glass disk. With an arc of ordinary intensity in the center of the mirror system, it is evident that the left half of the sectorized disk receives a flux of light about equal to that which it would normally receive with the longitudinal screen in position and the mirrors entirely uncovered. At the same time, no direct light from the images falls upon the photometer screen. Any illumination perceived under such circumstances would be due to the diffusive action of the glass. As a matter of fact, I found that with the temporary standard stopped down by a narrow slit, I could get a setting in this way when the sectorized wheel was not in position, but when this wheel was running in its proper place the correction was entirely negligible. Hence no further attempt was made to take account of it.

The distance from source to photometer screen is large, being nearly nine metres. As the incidence of the light from the temporary standard is the same as that from the arc, no correction is here necessary.

A working equation may be developed as follows: Let

d_a = distance from arc to photometer screen.

d_s = distance from temporary standard to photometer screen.

K_0 = reflection constant of the horizontal mirror.

K_g = transmission constant of clean glasses.

K_m = reflection constant of mirror on glow lamp side.

K_w = transmission constant of wheel.

n, n' = number of mirrors.

f = factor due to the lack of normal incidence.

The illumination due to the arc is

$$i = \frac{2 K_0 K_g K_w f \sum_0^\pi I_\theta \sin \theta}{d_a^2}$$

and that due to the standard of intensity I_s

$$i_s = \frac{f K_s I_s}{d_s^2}$$

Equating these two expressions, we have for the mean spherical intensity

$$\begin{aligned} I_{ms} &= \frac{\pi}{2n} \sum_0^\pi I_\theta \sin \theta \\ &= \frac{\pi K_s}{4n K_0 K_g K_w} \left(\frac{d_s}{d_s} \right)^2 I_s \end{aligned}$$

Similarly for the mean hemispherical

$$\begin{aligned} I_{mh} &= \frac{\pi}{2n'} \sum_0^{\pi/2} I_\theta \sin \theta \\ &= \frac{\pi K_s}{4n' K_0 K_g K_w} \left(\frac{d_s}{d_s} \right)^2 I_s \end{aligned}$$

With the following numerical values

$$\begin{array}{ll} d_s = 865 \text{ cm.} & n = 12 \\ & n' = 7 \\ K_0 = .812 & K_s = .901 \\ K_g = .690 & K_w = .090 \end{array}$$

These equations reduce to

$$I_{ms} = 1.17 \left(\frac{865}{d_s} \right)^2 I_s$$

$$I_{mh} = 2.01 \left(\frac{865}{d_s} \right)^2 I_s$$

which are the working equations for the apparatus. Values of d_s are recorded on a drum in a manner already described by the writer.¹ (See Fig. 2.)

Values of $\left(\frac{d_s}{d_s} \right)^2$ are obtained by laying a graduated T-

1. *Physical Review*, vol. vii, p. 239, 1898.

FIG. 5.—Specimen Record from Recording Drum.



square on the records obtained on the recording drum. A single covering on the drum suffices for the record of many tests. The records may then be worked out at the leisure of the operator. These records have always the same general characteristics, namely, many settings close together with scattered settings at each end. Figure 5 is a specimen record, and shows the usual range of fluctuation. The number of settings here is 30. This large number is necessary because of the fluctuations in the intensity of the arc, even with the steadying effect peculiar to the multiple mirror method. With hand fed arcs, a smaller number will suffice to give a value representative of the average performance of the arc. For the distribution curves, it suffices to uncover the mirrors in pairs and make settings in the usual way. The appropriate mirror constants must, of course, be used in working up the results.

As a check on the accuracy of the integrating method as compared with the usual method, I give the results of a test on an arc of the enclosed type. The value obtained from the Rousseau diagram is 308. That by the method described in this paper, 319. This agreement is within 3.4 per cent. When one considers the difficulty in maintaining an automatic feed arc under constant conditions during the time required to take the distribution curve, this must be considered as a very satisfactory agreement.

APPENDIX.

The product of the intensity I and the area of an elementary zone of radius r is

$$\begin{aligned} I_{\theta} dS &= I_{\theta} \times 2\pi r R d\theta \\ &= 2\pi R^2 I_{\theta} \sin \theta d\theta. \end{aligned}$$

The mean spherical intensity is

$$I_{ms} = \frac{\int I_{\theta} dS}{4\pi R^2} = \frac{1}{2} \int_0^{\pi} I_{\theta} \sin \theta d\theta.$$

The graphic method due to Rousseau is shown in Fig. 6. $O a b$ is the given distribution. Draw a semi-circle of convenient radius. Project on the vertical $c d$ the points h, k . At f, g , lay off the corresponding intensities I_1, I_2 . The area $c m n p d$

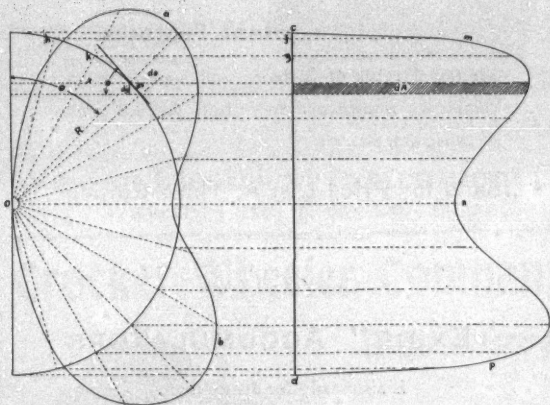


FIG. 6.

may be taken with a planimeter. This area divided by the base $c d$ gives the mean spherical intensity, for

$$d\theta = \frac{ds}{R}$$

$$ds \sin \theta = dy$$

$$I_{ms} = \frac{1}{2R} \int_0^{2R} I_{\theta} dy = \frac{A}{2R}.$$

B 42

A NEW PRICE LIST

OF THE

"Chloride Accumulator"

(Superseding all former issues,) has just been received from the press and is ready for distribution. This list embodies many

New and Important Features,
additional types of batteries and appurtenances, completely revised and more fully detailed tables of capacities, etc., etc.

Send for Price List A, Third Edition.

Our Price List of

"EXIDE" ACCUMULATORS

is also ready for distribution.

THE ELECTRIC STORAGE BATTERY CO.,

ALLEGHENY AVENUE AND 19TH STREET,

Philadelphia, Pa.

SALES OFFICES:

NEW YORK.	BALTIMORE.	CLEVELAND.	BOSTON.	CHICAGO.
100 Broadway	Equitable Bldg.	New England Bldg.	60 State St.	Marquette Bldg.
ST. LOUIS.	SAN FRANCISCO.	PHILADELPHIA.	DETROIT.	
Wainwright Bldg.	Nevada Block	Allegheny Av. & 19th St.	Michigan Electric Co.	

B46

WESTON STANDARD PORTABLE

DIRECT READING

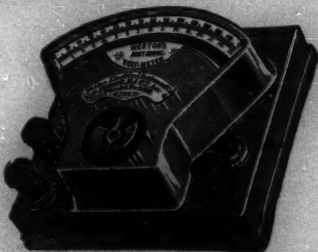
Voltmeters

—AND—

Ammeters

FOR ALTERNATING AND DIRECT
CURRENT CIRCUITS.

The only STANDARD PORTABLE
instruments of the type de-
serving this name.



Weston Standard Portable, Direct Reading Voltmeter.

MILLIVOLTMETERS, VOLTAMMETERS, AMMETERS, MILLIAMMETERS,
GROUND DETECTORS AND CIRCUIT TESTERS, OHMMETERS,
PORTABLE GALVANOMETERS, etc.

Our Portable Instruments are recognized as the Standard the world over. The Semi-
Portable Laboratory Standards are still better. Our Station Voltmeters and Amme-
ters are unsurpassed in point of extreme accuracy and lowest consumption of energy.

Weston Electrical Instrument Co.
Waverly Park, Essex Co., N. J.

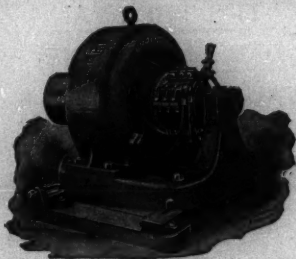
Crocker-Wheeler Company,

Manufacturers

AND

Electrical Engineers

Direct Current Ma-
chinery for all Pur-
poses.



WRITE FOR BULLETIN AND PRICES.

MAIN OFFICES AND WORKS,

AMPERE, N. J., U. S. A.

Branch Offices and Representatives in all Principal Cities.

PATENT EXPERT.

Chas. L. Clarke, C. E.,
Consulting Electrical Engineer.
31 Nassau St., New York.

ELECTRICAL CASES A SPECIALTY.

**MODELS,
EXPERIMENTAL WORK,
SUPPLIES,**

Manufacturers and Inventors
Electric Co.,

Store, 82 & 84 Nassau St.,
Factory, 96 & 98 Fulton St., N.Y.

"WHERE THE FAN GOES AROUND."

THE AMERICAN BELL TELEPHONE COMPANY

125 MILK STREET, BOSTON, MASS.

B
2330
This company owns Letters-Patent No. 463,569
granted to Emile Berliner November 17, 1891, for a
combined telegraph and telephone, covering all forms
of microphone transmitters or contact telephones.

McINTOSH, SEYMOUR & CO.

B
2559
AUBURN, N. Y.

—BUILDERS OF—

Engines FOR ALL **Electrical Purposes.**

YOUR ELECTRICAL LIBRARY

Should contain Bound Volumes of

LEADING PERIODICALS.

If your sets are incomplete, write for prices on the missing volumes or numbers. I have 100,000 numbers in stock of all American, English, German and French electrical papers and transactions of societies. I also have

FOR SALE

ELECTRICAL WORLD, complete sets, vols. 1 to 37.

ELECTRICAL ENGINEER, N. Y., complete set, vols. 1 to 27.

ELECTRICAL REVIEW, N. Y., complete set, vols. 1 to 36.

ELECTRICITY, complete set, vols. 1 to 19.

WESTERN ELECTRICIAN, complete set, vols. 1 to 27.

AMERICAN ELECTRICIAN, complete set, vols. 8 to 12.

FORTSCHRITTE DER ELEKTROTECHNIK, complete set, 1887-1900

TRANSACTIONS AM. INST. ELEC. ENGS., complete set, cloth, vols. 1 to 17.

JOURNAL INSTITUTION OF ELEC. ENGS., London, complete set, vols. 1 to 29.

LA LUMIERE ELECTRIQUE, Paris, complete set, vols. 1-53

ENGINEERING MAGAZINE, complete set, vols. 1 to 19.

CASSIER'S MAGAZINE, vols. 6 to 18.

Also long stretches of consecutive volumes of the following:

Electrician, London.
Electrical Review, London.
Electrical Engineer, London.
Engineering, London.
Science Abstracts, London.
Journal of the Society of Arts, London.
American Machinist, N. Y.
Engineering News, N. Y.
Engineering Record, N. Y.
Street Railway Journal, N. Y.
Street Railway Gazette, N. Y. and Chicago.

Electrical Engineering, Chicago.
Electrical Industries, Chicago.
L'Eclairage Electrique, Paris.
L'Electricien, Paris.
Journal of the Franklin Institute, Phila.
Scientific American, N. Y.
Transactions of the Royal Society of London.
Proceedings of the Royal Society of London.
Philosophical Magazine, London, and many others.

1,000 ELECTRICAL PAMPHLETS.

Catalogue in preparation. Send for it if you are interested.

EDWARD CALDWELL, ROOM 1930 150 NASSAU ST., N. Y.

B 35

WESTINGHOUSE

Electric Apparatus

Westinghouse Electric & Mfg. Co.

PITTSBURG, PA.

All Principal Cities in U. S. and Canada.

B 39

Westinghouse, Church, Kerr & Co.

ENGINEERS,

New York, Boston, Philadelphia, Pittsburg, Chicago, Detroit.

Power Plants from Inception to Completion.

One Management.



One Responsibility.

Prices and specifications furnished.

Also Sell the Product of

The Westinghouse Machine Co.

Pittsburg—Designers and Builders—Chicago

—OF—

Westinghouse Junior, Standard, Compound and Corliss
Steam Engines; Gas Engines, Roney Mechanical Stokers,

160 A.

Steam Turbines, etc., etc.

Report of Committee on the Standardization

OF

ELECTRIC GENERATORS, MOTORS AND TRANSFORMERS.

This Report which has been in preparation since January 1898, has now been published for general distribution. It is receiving the endorsement of leading manufacturers and engineers.

Single Copies Postpaid, 10c. each. In quantities of 10 or more 5c. each.

Address **R. W. POPE, Secretary,**
26 Cortlandt St., New York City



The Institute Badge.

The Council has authorized the sale of Badges of the new design at the following prices, for the different styles.

Vest Pin, - - - - -	\$3.00
Scarf Pin, - - - - -	3.00
Watch Charm, - - - - -	3.00
Lapel Button, - - - - -	4.00

All of the above patterns are of solid 14k gold and finely finished. The enamel is blue for Members, and maroon for Associate Members. One dollar will be allowed for the old badge when returned. The initials or full name as desired, will be engraved on the back together with serial Number.

Address,

R. W. POPE, Secretary.
26 Cortlandt St., New York.

COPPER WIRE TABLE.

This table gives the WEIGHTS, LENGTHS and RESISTANCES of cool, warm, and hot wires of

MATTHIESSEN'S STANDARD CONDUCTIVITY.

for both Brown and Sharpe (A. W. G.) and Birmingham Wire Gauges (B. W. G.)

It was prepared by the Institute Committee on Units and Standards, personally revised by the individual members of the Committee, and issued with the October, 1893, number of the TRANSACTIONS, forming a part of Volume X.

Mailed separately, price 10 cents.

RALPH W. POPE, Secretary,
26 Cortlandt Street,
New York City.

JOHN A. ROEBLING'S SONS CO

MANUFACTURERS OF

HIGH TENSION CABLES

WITH

Paper and Rubber Insulation for any
Voltage

TELEPHONE CABLES

Waterproof
Wire

Magnet
Wire

IRON, STEEL AND COPPER
WIRE

WIRE ROPES FOR ALL PURPOSES

MAIN OFFICE AND WORKS, TRENTON, N. J.

Branch Offices and Stores,

NEW YORK.

CHICAGO.

CLEVELAND.

SAN FRANCISCO.